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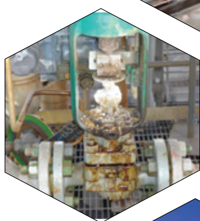

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Editor's Page

Innovations in 'green' chemistry

Striving to make products and processes safer, more efficient, more sustainable, more economical and more environmentally friendly has long been the goal of research and applied scientists and engineers. For the past 28 years, new and innovative "green" chemistry technologies have been recognized by the Green Chemistry Challenge Awards. The U.S. Environmental Protection Agency (EPA; www.epa.gov) recently announced this year's winners.

Submissions were judged by an independent panel of technical experts convened by the American Chemical Society Green Chemistry Institute (ACS; www.acs.org), who made recommendations to the EPA. Award recipients were recognized on September 26 in New York City. The following are the 2024 winners (Source: EPA):

Greener Synthetic Pathways — Merck & Co., Inc. (Rahway, N.J.; www.merck.com) was recognized for its development of a continuous process for manufacturing pembrolizumab, tradenamed KEYTRUDA®. Pembrolizumab works by increasing the ability of the body's immune system to help detect and fight tumor cells. Typically, this type of protein is made in batches. Merck developed a continuous process that removes the protein from the producing cells continuously rather than by batch filtration. This allows smaller equipment to be used, reduces energy and water use and thereby reduces emissions.

Design of Safer and Degradable Chemicals — This award went to **Pro Farm Group** (Davis, Calif.; www.profarmgroup.com), a subsidiary of Bioceres Crop Solutions, for its microbial pesticide, Rinotec™, which is based on a microbe with natural pesticidal effects. After growing the microbe in large vessels, it is killed and used in a treatment to coat seeds prior to planting. The company says the product is biodegradable and can replace several commonly used synthetic pesticides. Pro Farm Group engineered its fermentation process to increase production of the key pesticidal metabolite, which allows for a substantially reduced application rate compared to a previous product, reducing the amount of product released into the environment.

Specific Environmental Benefit – Climate Change — PhoSul® (Sugar City, Idaho; www.phosul.com) received this award for developing an enhanced phosphate rock fertilizer. Phosphate that is usable by plants as a fertilizer is currently produced from phosphate rock that is processed with acids. The process produces a gypsum waste stream that contains heavy metals. PhoSul has developed a method to use phosphate rock directly by enhancing it with other materials. The additives allow the phosphate in the rock to be converted into forms that are available to plants in the soil without the use of acids, thus avoiding associated hazardous wastes and emissions.

Academic Category — University of Delaware (Newark, Del.; www.udel.edu) chemical and biomolecular engineering professor **Dionisios Vlachos** was recognized for developing new synthetic methods to produce lubricant base oils from plant or food waste biomass instead of petroleum-based feedstocks. The innovative process uses sugars as a starting point and a solid catalyst, which allows milder reaction conditions compared to existing bio-based lubricant production.

Small Business Award — This award went to **Viridis Chemical Co.** (Columbus, Neb.; www.viridischemical.com) for developing a catalyst and process to produce ethyl acetate from corn instead of from coal or methane feedstocks. The process also produces H_2 gas as a byproduct, which can be used in energy generation. ■

Dorothy Lozowski, Editorial Director

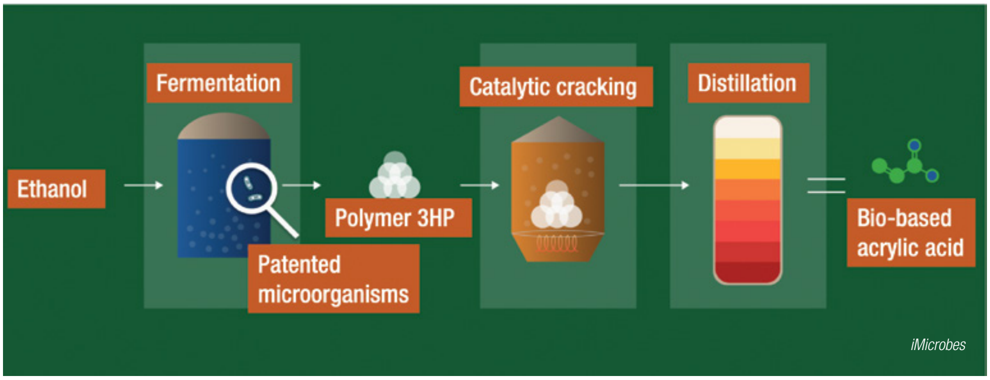
A low-cost method for bio-based production of acrylic acid

Acrylic acid, a commodity chemical used widely in superabsorbent polymers, paints, coatings, adhesives and more, is typically produced from fossil-based propylene at relatively high temperatures. As part of an initiative supported by the U.S. Dept. of Defense, funding was recently awarded to Industrial Microbes, Inc. (iMicrobes; Alameda, Calif.; www.imicrobes.com) towards commercializing a new bio-based manufacturing process for acrylic acid that reduces both the cost and carbon footprint (diagram). "We are using the support to plan our first commercial facility that will use a fermentation process to convert ethanol into acrylic acid and derivatives," says Noah Helman, iMicrobes CEO. The company has engineered microorganisms to consume plant-based ethanol as a carbon and energy source. Within a proprietary engineered bacterial cell, an intermediate polymer (a polyester of 3-hydroxypropionate, or P3HP) is readily accumulated as fermentation takes place. "That polymer can be converted to acrylic acid via a very simple catalytic cracking process. With heating to a moderate temperature, the catalyst decomposes the polymer into acrylic acid vapors, which can be captured and purified using standard unit operations like distillation," says Helman.

In June, iMicrobes began scaling up the process at a facility in Emeryville, Calif., operating at the kilogram scale for the first time outside of the laboratory. "Then, in August, with support from BioMADE, we began operating that same process in a 1,500-L fermenter at a site in Illinois, generating several more kilograms of product," adds Helman.

The key to the process' efficiency is the accumulation of the intermediate polymer, which is generated at very high concentrations inside the bacterial cell. "In our cost modeling, we estimate that we should be able to produce acrylic acid at about 20% lower cost than today's existing methods, and the carbon footprint should be reduced by 75% or even more, depending on the source of the ethanol," says Helman.

The first applications for iMicrobes' acrylic acid products will be in consumer personal-care products, where bio-based raw materials carry a particular premium, and the company is also looking at routes to additional products beyond acrylic acid.



'Frugal' method adsorbs and destroys PFAS with photocatalyst

Removing per- and polyfluoralkyl substances (PFAS) from surface and groundwater has become an environmental and public health imperative, but methods for doing so are often complicated and costly, and may not destroy the molecules. Researchers at the University of British Columbia (UBC; Vancouver, B.C.; www.ubc.ca) have developed a hybrid iron-oxide and graphenic-carbon photocatalyst that can degrade PFAS efficiently in the presence of ultraviolet (UV) light.

The UBC system combines an activated carbon filter, which adsorbs the PFAS species, with its patented photocatalyst, which destroys the PFAS molecules. "We can put huge volumes of water through this catalyst, and it will adsorb the PFAS and destroy it in a quick two-step process," says Johan Foster, UBC professor of chemical and biological engineering. "Many existing solutions can only adsorb [PFAS], while others are designed to destroy the chemicals. Our catalyst system can do both."

The UBC work involves immobilizing a photoactive iron oxide on solid surfaces of mesoporous carbon. The researchers developed a "frugal" approach for preparing the photocatalyst that takes advantage of iron oxide, which is known for its photoactivity and ability to drive charge separation.

In tests, the UBC system demonstrated the ability to capture and destroy up to 90% of perfluorooctanoic acid, a common PFAS pollutant, in 3 hours under UV light. "The catalyst is not limited by ideal conditions," explains Raphaell Moreira, a professor at the Universität Bremen who conducted the research while working at UBC. "Its effectiveness under varying UV light intensities ensures its applicability in diverse settings, including regions with limited sunlight exposure." The catalyst also maintains high degradation rates over extended periods, demonstrating its stability and potential for long-term use, the researchers say.

The UBC team believes their catalyst could be a low-cost solution for municipal water systems, as well as specialized industrial projects, like cleaning up PFAS-containing waste streams. The researchers have set up a company, known as ReAct Materials, to explore commercial opportunities for the technology. Details of the work were published recently in the *Nature* journal *Communications Engineering*.

Process for electrolytically converting CO_2 to carbon materials to be scaled up

With a recent round of investment funding, UP Catalyst (Tallinn, Estonia; www.upcatalyst.com) plans to build a pilot plant for a process that converts waste carbon dioxide into a range of solid carbon materials, such as carbon nanotubes, (CNTs), graphite and carbon black. The pilot plant, anticipated to start up before the end of 2025, will produce about 100 kg/day of solid carbon, a factor of 10 greater than the current pre-pilot production, says Sebastian Pohlmann, chief technology officer at UP Catalyst.

UP Catalyst's process uses molten carbonate salt to dissolve CO_2 from hard-to-abate industrial processes, such as waste incineration. To work effectively, the CO_2 must first be purified to above 98% via an amine wash. Once purified, CO_2 is pumped into the molten salt, where an electric current is applied across electrodes in the salt. In order to synthesize certain carbon allotropes, a metallic catalyst is also present in the molten salt. The applied current drives an electrolysis reaction where CO_2 is split into O_2, which is released, and solid carbon, which accumulates on the cathode of the reactor cell, and is mechanically removed.

"By carefully controlling the reaction conditions, including temperature, as well as which catalysts and electrolytes are used, we can dictate the properties of the resulting solid carbon products, and we are aiming for production at price parity for traditional carbon sources," says Pohlmann.

Among the key engineering challenges UP Catalyst overcame in developing the process is an effective method of introducing the catalyst into the system that avoids having the metals end up in the solid carbon products. Also, the company developed a method for recovering and recycling the molten salt as the reactor cell operates.

There are three general categories for the products made by UP Catalyst's process: graphite for use in battery electrodes for electric vehicle and stationary storage; CNTs as additives for polymers, paints and cement; and carbon black for paints and coatings.

"The process addresses two growth markets simultaneously," Pohlmann explains. "We are capturing carbon that would otherwise end up in the atmosphere, and upcycling it to produce solids that fit into a range of performance materials."

The carbon footprint associated with producing graphite using UP Catalyst's process is 20 times lower than conventional graphite production, according to UP Catalyst, and emissions for making CNTs are 242 times lower than emissions from the traditional chemical vapor deposition method.


UP Catalyst

A nearly universal electrolyte chemistry for safer, longer-lasting batteries

The electrolytes used in nearly all lithium-ion and sodium-ion batteries are carbonate-based, which makes them flammable and prone to degradation mechanisms, including side reactions, which can result in gas evolution and the formation of undesirable chemicals like hydrogen fluoride. A proprietary, nonflammable electrolyte developed by Elementium Materials, Inc. (Somerville, Mass.; www.elementium.io) avoids such failure mechanisms and is said to be compatible with nearly any battery chemistry, while also providing a higher energy density.

"Our electrolyte technology is compatible with legacy electrode materials like LFP [lithium-iron-phosphate] and graphite, and also with emerging electrode chemistries, including silicon-based, manganese-rich and high-nickel formulations, as well as sodium-ion and semi-solid-state applications," explains Matthew Dawson, CEO of Elementium Materials.

The key to the electrolyte and its near-universal compatibility is a novel sulfonamide-based solvent system and a relatively simple, single-step, liquid-phase synthesis platform that doesn't require particularly high temperature or pressure. "We have a very scalable synthesis process, and currently, we just make whatever we need for our validation projects in 1-kg batches. We have plans in 2026 to build a 1 million-kg/yr commercial pilot plant that would be able to service about half a gigawatt-hour worth of batteries," says Dawson.

Because batteries using this electrolyte are more stable and have a longer lifespan, they can be operated at higher voltage, using the electrode material more efficiently, resulting overall in smaller and lower-cost batteries. Elementium validated its electrolyte in third-party pouch cells. "We tested pouch cells at 4.7 V with a major automaker, using our electrolyte versus their conventional systems, and observed significant improvements in longevity and performance. We also have had tests in sodium-ion batteries where we've shown the potential to operate at 4.8 V very stably, whereas other similar batteries traditionally operate at around 3.4 V," adds Dawson.

Destroy PFAS while also producing syngas

The destruction of per- and polyfluoroalkyl substances (PFAS) presents unique issues in wastewater treatment, as these substances are persistent in many treatment environments, and PFAS-laden purification media is challenging to dispose of. Now, InEnTec Inc. (Richland, Wash.; www.inentec.com) says that its plasma-gasification system can provide comprehensive PFAS destruction, while also producing a syngas (H_2 + CO) byproduct stream. "Our plasma system uses Joule heating with a molten bed of glass in the reactor chamber. On top of that molten bed of glass, we generate plasma with direct current between graphite electrodes. It's very unique in that it's a completely sealed reactor chamber, and the concept of combining Joule heating with plasma heating makes it very efficient in comparison to other plasma technologies," explains Jeff Surma, CEO of InEnTec. In addition to lower energy requirements, the design of InEnTec's plasma system enables it to process fluorinated compounds without the corrosion issues other plasma-based systems might encounter.

"We create this really high-temperature, reactive environment with ionized gas and hydrogen radicals. The presence of these hydrogen radicals helps to assist in the conversion of the carbon-fluoride bond to a hydrogen-fluoride bond. Then, the carbon gets converted into either CO or CO_2, depending on where we're running the system from an oxidation-reduction standpoint," says Surma. Operating in a more reduced mode promotes the formation of syngas, which helps to lower operating costs by producing a useful byproduct simultaneously with PFAS destruction.

The unit's primary plasma chamber is where the majority of destruction takes place, and a downstream thermal-residence chamber keeps the syngas at a high temperature for greater than 2 seconds. The hydrofluoric acid resulting from PFAS destruction is neutralized into sodium fluoride.

In recent trials with Terre Environmental LLC, the plasma unit demonstrated greater than 99.999999% (eight 9s) destruction and removal efficiency (DRE) while processing granular activated carbon (GAC) loaded with PFAS at a level that would typically exhibit breakthrough in commercial water-treatment systems. With InEnTec's system, the GAC is converted into syngas and the PFAS compounds are destroyed.

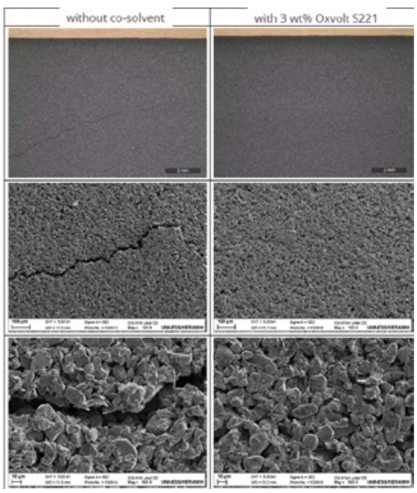
InEnTec

A non-toxic co-solvent makes batteries safer and more efficient

The solvent N-methylpyrrolidone (NMP) has been used to coat anodes and cathodes in lithium-ion batteries, but it has been shown to be a reproductive toxin, necessitating controlled handling and recycling within a closed system, which adds complexity and cost to battery production. Today, NMP can be replaced by water for graphite anode production. A new co-solvent for water-based electrode coatings launched by OQ Chemicals (Monheim am Rhein, Germany; chemicals.oq.com), Oxvolt S221, is readily biodegradable and non-toxic — and crucially, helps to improve battery performance by preventing crack formation on the electrode surface. "Oxvolt S221 has a boiling point similar to NMP. As a coalescing agent, it supports the formation of homogenous layers, particularly with high-thickness coating layers. It helps to improve the processability of coated layers and prevents crack formation at higher coating thicknesses. Cracks are not tolerable, and lead to wasted materials," explains Claudia Fischer, director of global business development at OQ Chemicals. The ability to support thicker coating layers ultimately leads to increased energy density within battery cells, adds Fischer.

Oxvolt S221 lowers the viscosity of the slurry and enhances processing by improving mixing properties and the quality of the electrode after coating and initial drying stages. It is water-soluble and is added to water as a co-solvent at low percentages, completely evaporating during the drying process. In tests conducted at Karlsruhe Institute of Technology (KIT; www.kit.edu), utilizing a coating solution with 3% Oxvolt S221 co-solvent in a roll-to-roll manufacturing process for graphite anodes significantly reduced the formation of cracks on the anode surface (see picture), with a wet coating thickness around 300–340 µm and a coating speed of 0.2 m/min.

Oxvolt S221 has also been tested by Germany battery firm CustomCells, demonstrating the potential to increase the overall efficiency of graphite anode production when compared to conventional water-based coatings systems, with no detrimental impact on the electrical properties and lifetime of the battery cells. "Oxvolt S221 is approved by several battery cell producers for graphite anode materials. We have started testing it in other water-based battery processes, such as lithium-iron-phosphate (LFP), and there is still more development needed," says Fischer. Oxvolt S221 is globally available and currently being produced at the commercial scale by OQ Chemicals in the U.S.



KIT

New method lowers energy required for production of cellulose nanofibers

Because of their excellent mechanical properties, light weight and biodegradability, cellulose nanofibers (CNF) are attractive materials for next-generation reinforced biomaterials and bioplastics. However, the method for separating cellulose to make CNF, known as fibrillation, is energy-intensive, which limits applications for CNF. Now, in a collaborative project, scientists from the Oak Ridge National Laboratory (ORNL; Oak Ridge, Tenn.; www.ornl.gov), along with teams from the University of Tennessee (Knoxville; www.utk.edu) and the University of Maine (Orono; www.umaine.edu), have developed a method for lowering the energy required to produce CNF from cellulose.

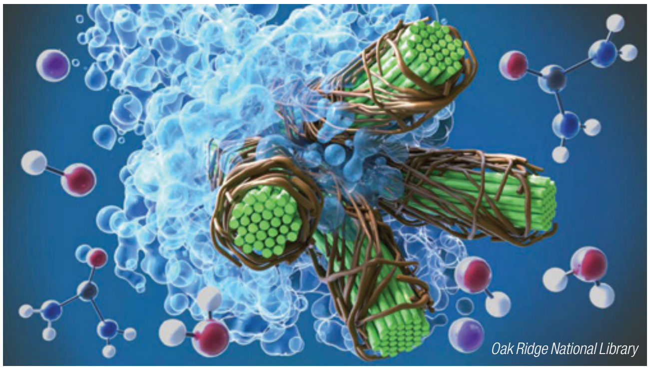
First, the researchers used atomistic molecular dynamics simulations to explore candidate solvents that would "facilitate the reduction of interactions between cellulose fibers, thereby reducing energy consumption in fibrillation," they write. According to the simulation studies, the most suitable medium for fibrillation of cellulose is an aqueous solution of sodium hydroxide and urea in a particular ratio (0.007:0.012 wt.%).

Next, the scientists conducted pilot studies using the NaOH/urea solution, and found that fibrillation energy was reduced by about 21% on average, compared to water alone. The research team explains: The NaOH and urea "act synergistically on CNFs to aid fibrillation, but at different length scales. NaOH deprotonates hydroxyl groups, leading to mesoscale electrostatic repulsion between fibrils, whereas urea forms hydrogen bonds with protonated hydroxyl groups, thus disrupting inter-fibril hydrogen bonds."

The researchers say the method significantly lowers the production cost of CNF — an ideal biomaterial to use as a composite for 3D-printing structures, such as sustainable housing and vehicle assemblies. With the "winning" solvent, the team estimates the electricity savings potential could amount to about 777 kilowatt hours per metric ton CNF produced.

Testing of the CNF derived from this new method found similar mechanical strength and other desirable characteristics compared with conventionally produced CNF.

The research was published in a recent issue of the *Proceedings of the National Academy of Sciences*. ■



Oak Ridge National Library

Chementator Briefs

ELECTRIFYING INDUSTRIAL HEAT

Calectra (Oakland, Calif.; www.calectra.com) has received $1.6 million in pre-seed funding and $400,000 in grant funding from the U.S. Government and New York State to support its work on decarbonizing industrial process heat. Heavy industrial processes, like steel, cement and glass manufacturing require high-temperature heat. Electrifying these processes to reduce carbon emissions with currently available solutions, such as using green hydrogen is prohibitively expensive. Calectra is developing a power-to-heat thermal storage technology to provide manufacturing industries with low-cost, high-temperature (up to 1600°C), emission-free process heat. The company's thermal storage system converts electricity from the grid or on-site renewables into high-temperature heat within its patent-pending bricks. This heat is then stored in the bricks and delivered to industrial manufacturers on demand. Calectra optimizes its technology for high-temperature heat delivery at low cost and at large scale. Nate Weger, co-founder and chief technical officer CTO of Calectra, developed the technology concept while at UC Berkeley and the Lawrence Berkeley National Laboratory.

The company says that replacing fossil fuels in high-temperature process-heat generation could cut CO_2 emissions by 1.8 gigatons per year, which represents about 5% of global CO_2 emissions.

CHEAPER CATHODE MATERIALS

Currently, electric vehicle (EV) batteries carrying lithium manganese iron phosphate (LMFP) cathodes are less expensive than those with nickel cobalt manganese (NCM) cathodes, but are not able to achieve the energy density of NCM-based batteries. Now, Integrals Power (Milton Keynes, U.K.; www.integralspower.co.uk) has developed technology for LMFP cathode active material that avoids this tradeoff, allowing the lower-cost battery chemistries to achieve the performance characteristics of batteries with the more expensive NCM cathode chemistry.

Applying its propriety materials technology and patented manufacturing process, the company has overcome the drop in specific capacity that typically occurs as the percentage of manganese in the cathode is increased. The result is a cathode active material that supports higher voltages and high energy density, Integrals Power says. For EVs, the implications of this advance are that vehicle range could increase by up to 20%, or — for a given range — battery packs could be smaller and lighter.

The Integrals Power technology allows LMFP cathode materials with 80% Mn, as opposed to the 50–70% typically found in competing materials, and have higher specific capacity (150 mAh/g), while delivering a voltage of 4.1V (versus 3.45V for LFP cathodes). Third-party testing at the Graphene Engineering Innovation Centre (GEIC) has been completed on coin cells and is now ongoing for EV-representative pouch cells.

CO_2 TO PROTEIN

LanzaTech Global (Skokie, Ill; www.lanzatech.com) has developed a process that uses CO_2 to produce LanzaTech Nutritional Protein (LNP). The company reports that it has operated a pilot plant for two years, and is now moving to the engineering design phase for a 0.5 to 1.5 tons per day facility, expected to be operational in 2026. Commercial-scale facilities are being designed for 30 metric tons per year (m.t./yr) and production is expected by 2028.

LNP is a nutrient-rich microbial protein with a complete amino-acid profile alternative to plant- and animal-based foods. Using its proprietary gas-fermentation process, with a new microbe, the company says LNP can be a cost competitive alternative to plant- and animal-based proteins. ❒

Business News

Plant Watch

BASF completes superabsorbent polymers expansion project in Texas

October 16, 2024 — BASF SE (Ludwigshafen, Germany; www.basf.com) announced that its petrochemicals division has completed production upgrades for superabsorbent polymers (SAP) after a $19.2-million investment in its Freeport, Tex. site. The project, which began in 2023, involved the installation of new equipment to increase production rates and the optimization of existing processes at the SAP plant, ultimately resulting in up to 20% higher throughput.

Mitsubishi Chemical Group expands production of ion-exchange resins

October 16, 2024 — The Mitsubishi Chemical Group (MCG; Tokyo; www.mcgc.com) has decided to increase its production capacity of ion-exchange resins at the Kyushu-Fukuoka Plant in Kitakyushu City, Japan. The upgraded facilities are scheduled to go into operation in April 2026. MCG's ion-exchange resins are used in various applications, including the production of industrial water, the refining of pharmaceuticals and food products and the production of ultrapure water for semiconductors.

Air Liquide to supply oxygen to LG Chem for battery plant in Tennessee

October 16, 2024 — Air Liquide S.A. (Paris; www.airliquide.com) will invest around $150 million to expand its production capacity and pipeline network in Clarksville, Tenn. to supply oxygen for LG Chem Ltd.'s (Seoul, South Korea; www.lgchem.com) cathode active material plant. This investment involves the construction of a second air-separation unit at the site, as well as additional liquefaction, storage and pipeline capacities. The expansion is expected to be commissioned in 2027.

DuPont completes expansion of photoresist facility in Japan

October 4, 2024 — DuPont (Wilmington, Del.; www.dupont.com) completed a significant expansion for photoresist manufacturing capacity at an existing DuPont site in Agano-shi, Niigata, Japan. With this expansion, DuPont has now nearly doubled its photoresist production capacity at the site, also adding new cleanroom capabilities to reduce contamination risks.

Evonik breaks ground on major silica expansion in South Carolina

October 2, 2024 — Evonik Industries AG (Essen, Germany; www.evonik.com) broke ground on a significant expansion project at its site in Charleston, S.C. This new development will boost the production capacity of precipitated silica by 50%.

Fujifilm to expand semiconductor materials business in Japan

September 30, 2024 — Fujifilm Corp. (Tokyo; www.fujifilm.com) invested ¥20 billion (around $133 million) in its semiconductor materials business to further strengthen its facilities for the development, production and quality evaluation of advanced semiconductor materials in Shizuoka and Oita, Japan. The new unit at the Shizuoka site is scheduled to begin operations in late 2025, and the new unit at the Oita site is scheduled to begin operations in early 2026. Fujifilm's slate of semiconductor chemicals includes photoresists, photolithography-related materials, chemical-mechanical planarization materials, thin-film chemicals and polyimides.

HIF Global announces e-methanol project in Brazil

September 27, 2024 — HIF Global (Houston; www.hifglobal.com) plans to develop a facility to produce up to 800,000 metric tons per year (m.t./yr) of e-Methanol — its first project in Brazil. To be located at the Port of Açu, located in the state of Rio de Janeiro, the plant will use electrolyzers to produce "green" hydrogen, which will be combined with recycled CO_2 to form e-methanol.

Avient to expand medical TPU production capacity in China

September 26, 2024 — Avient Corp. (Cleveland, Ohio; www.avient.com) is expanding its manufacturing capabilities for thermoplastic polyurethane (TPU) at its plant in Suzhou, China. The TPU products at this site are primarily used in catheter applications, including cardiovascular, intravenous and other specialty segments.

Mergers & Acquisitions

Phillips 66 to sell interest in Switzerland-based joint venture

October 16, 2024 — Phillips 66, Inc. (Houston; www.phillips66.com) entered into a definitive agreement to sell its 49% non-operated equity interest in Coop Mineraloel AG (CMA) to its Swiss joint venture (JV) partner for a sales price of approximately $1.17 billion. CMA focuses on mineral oil, as well as the procurement and sale of petroleum products (such as fuels and fuel oil), and also operates 324 retail sites and petrol stations across Switzerland. The transaction is expected to close in the first quarter of 2025.

Rio Tinto to acquire Arcadium Lithium for $6.7 billion

October 9, 2024 — Rio Tinto plc (London; www.riotinto.com) plans to acquire Arcadium Lithium plc (Philadelphia, Pa.; www.arcadiumlithium.com) in an all-cash transaction that values

LINEUP

Arcadium at approximately $6.7 billion. Arcadium has capabilities in lithium-chemicals manufacturing and extraction processes, including hard-rock mining, conventional brine extraction and direct lithium extraction. Arcadium's current production capacity is 75,000 m.t./yr of lithium carbonate equivalent, with expansion plans in place to more than double capacity by the end of 2028. Arcadium currently has projects in Argentina, Australia, Canada, China, Japan, the U.K. and the U.S.

McDermott announces agreement to sell CB&I storage business
October 8, 2024 — McDermott International, Ltd. (Houston; www.mcdermott.com) has agreed to sell its CB&I storage business to a consortium of financial investors led by Mason Capital Management. Under the terms of the agreement, McDermott expects to receive $475 million of proceeds before taxes and transaction expenses. CB&I is a designer and builder of storage facilities, tanks and terminals. It became part of McDermott in 2018 when the two companies combined.

Honeywell to spin off its Advanced Materials business
October 8, 2024 — Honeywell International, Inc. (Charlotte, N.C.; www.honeywell.com) plans to spin off its Advanced Materials business into an independent company, which is targeted to be completed by the end of 2025 or early 2026. Upon completion of the spin-off, the new company will operate in a number of sectors, including fluorine products, electronic materials, industrial-grade fibers and healthcare packaging.

Chandra Asri to acquire Shell Energy and Chemicals Park in Singapore
October 7, 2024 — Chandra Asri Group (Jakarta, Indonesia; www.chandra-asri.com) has agreed to acquire Shell Energy and Chemicals Park (SECP) in Singapore. Through the acquisition of SECP, Chandra Asri will ensure the supply of petroleum and chemical products, such as gasoline and jet fuel, as well as ethylene, polyethylene, propylene and styrene monomers, to support the needs of various local industries and processes.

Lanxess to sell Urethane Systems business to UBE Corp.
October 1, 2024 — Lanxess AG (Cologne, Germany; www.evonik.com) will sell its Urethane Systems business to UBE Corp. (Tokyo; www.ube.com). The enterprise value amounts to €460 million, with expected proceeds of €500 million. With this transaction, Lanxess exits its last remaining polymer business. The Urethane Systems business comprises five manufacturing sites, as well as laboratories in the U.S., Europe and China.

Covestro agrees to takeover deal by ADNOC at €62 per share
October 1, 2024 — Covestro AG (Leverkusen, Germany; www.covestro.com) signed an investment agreement with certain entities of the ADNOC Group (Abu Dhabi, United Arab Emirates; www.adnoc.ae) under which ADNOC will make a public takeover offer for all shares of Covestro at a price of €62.00 per share. This price implies an equity value for Covestro of approximately €11.7 billion. ■

Mary Page Bailey

Analyzers

A handheld Raman device for material identification

This company's handheld 1,064-nm Raman Progeny analyzer (photo) is used for raw material identification, in-process analysis and authentication of finished products in pharmaceutical manufacturing. Traditional processes can include laboratory analysis, a costly and time-consuming step. By implementing an analysis method at the point of need with a handheld tool that can be used by a non-scientist, manufacturers can benefit from a more efficient method to identify or verify their material in a shorter time frame, and at a lower cost when compared to laboratory analysis. With its advantage of utilizing a 1,064-nm Raman laser excitation, Progeny offers a unique solution for reducing fluorescence interference, a common obstacle among traditional handheld Raman devices. Users now have the ability to analyze a wider range of materials and obtain interference-free results in seconds. Other benefits include the ability to scan through translucent packaging, including polymer and glass materials, a smartphone-inspired user interface and a sealed IP-68 rating for rugged warehouse use. — *Rigaku Analytical Devices, Wilmington, Mass.*
www.rigakuanalytical.com

Rigaku Analytical Devices

A combustion analyzer for emissions monitoring

The Thermox WDG-V HP series (photo) is a set of next-generation high-particulate combustion analyzers. The series can be used to measure excess oxygen, combustible materials and hydrocarbons in industrial applications, including cement and lime kilns, power boilers, incinerators and others. The Thermox WDG-V HP builds on the company's WDG platform, but adds predictive artificial-intelligence diagnostics and design redundancies that increase reliability and worker safety. The analyzer is certified for use in hazardous areas (ATEX/IEC Ex Zone IIC T3 globally and Class I, Div. 2 in North America). The new series adds the capability of measuring hydrocarbons, including methane and other alternative fuels, such as methanol and hydrogen, at percent levels as a standard feature. This allows monitoring for excess fuel and loss of flame during startup and normal operation. There is also a more serviceable and robust enclosure, ensuring superior ingress protection and easier access to the probe and filter. — *Ametek Process Instruments, Berwyn, Pa*.
www.ametekpi.com

Ametek Process Instruments

A real-time analyzer for calculating O_2 in gas streams

The OxyHound (photo) is a highly-efficient process gas analyzer that conducts real-time and continuous oxygen analysis of natural gas, biogas and other gas streams. Utilizing optical quench luminescence technology for gaseous sampling, this cost-effective analyzer conducts precise oxygen measurements in a gaseous phase (ppmv and % on a molar basis) with no cross-sensitivity for CO_2, H_2S, NH_3 or SO_2, sulfate or other ionic species, the company says. The technology of the OxyHound is based on the phase modulation of an oxygen-specific luminophore's luminescent decay time, which enables accurate calculation of oxygen's partial pressure. The oxygen analyzer measures the phase shift and intensity variation between the excitation light and the fluorescent response, calculating oxygen in real time. The OxyHound eliminates the need for electrolyte changes or membrane maintenance. With the ability to work indoors and outdoors, the gas analyzer serves various industries, including natural gas pipelines, refineries, biogas, chemical plants, landfills, wastewater treatment, manufacturing, food and beverage and renewables. — *Analytical Systems Keco, Houston, Tex*.
www.liquidgasanalyzers.com

Analytical Systems Keco

This laboratory TOC analyzer is focused on ease of use

The multi N/C x300 product series (photo, p. 14) is designed for analysis of total organic carbon (TOC) and

Analytik Jena

ThermoFisher Scientific

Shimadzu Scientific Instruments, Inc.

Gasmet Technologies Oy

total nitrogen bound (TNb) in the environmental and pharmaceutical sectors. The company says these analyzers make everyday laboratory work easier for users thanks to their reliable technology and intuitive software. The device series is suitable for public and industrial laboratories, as well as research institutes, in the fields of environmental analysis and pharmaceuticals. The company offers a device specialized for each field of application, from a compact and robust specialist for particle-rich samples to an all-around instrument optimized for high throughput in standard environmental analysis, and an ultra-precise device that offers maximum sensitivity for trace TOC analysis. — *Analytik Jena, Thüringen, Germany*
www.analytik-jena.com

A new capability for this handheld XRF analyzer

This company announced a new capability — Light Metal Quick Sort — for its Niton XL5 Plus handheld X-ray fluorescence (XRF) analyzer (photo), enabling ultra-fast analysis of aluminum and magnesium alloy grades in under two seconds. This new mode, which can also identify high-value-alloy families of other light metals — including stainless steel, nickel, cobalt, copper and titanium — significantly reduces analysis times over traditional methods, offering a path to improved efficiency for scrap metal operations, the company says. The Niton XL5 Plus is the lightest, smallest and most powerful handheld XRF analyzer available for elemental determination in the field, offering non-destructive analysis of metals and alloys in seconds. The General Metals mode on the Niton XL5 Plus analyzer has been expanded to include an enhanced ability to detect low levels of nickel in low-alloy steels, along with a new mode for ultra-fast light-metals analysis. The new mode provides accurate analysis of Mg to concentrations as low as 0.5%. The product can aid metal recycling. — *Thermo-Fisher Scientific, Tewksbury, Mass.*
www.thermofisher.com/scrap

This partnership pairs HPLC with automatic sampling

A technology integration partnership combines this company's high-performance liquid chromatography (HPLC) analyzers with the DirectInject-LC, a technology for automatic sampling and reaction preparation made by Telescope Innovations (photo). HPLC is a gold-standard analysis technique in process chemistry, enabling researchers to separate and analyze each component in a chemical mixture. DirectInject-LC dramatically amplifies the power of this technology by automatically sampling and preparing reactions for real-time injection into HPLC instruments. Thus, full reaction profiles become readily accessible, providing rich chemical understanding, impurity profiling and fast optimization strategies, the companies say. This type of data-rich experimentation represents a massive competitive advantage to the pharmaceutical and chemical industries. —*Shimadzu Scientific Instruments, Inc., Columbia, Md*.
www.shimadzu.com

This portable FTIR analyzer receives QAL-1 certification

This company's portable Fourier transform infrared (FTIR) gas analyzer GT6000 Mobilis (photo), launched in 2023, recently received EN15267-4 QAL1 certification for portable automated measurement devices. The GT6000 Mobilis is the first FTIR portable analyzer to receive the certification. The EN15267-4 QAL1 certification enables users to ensure the reliability and accuracy of emissions-monitoring systems, which are crucial for regulatory compliance and environmental protection, the company says. The GT6000 Mobilis is designed to withstand varying gas matrixes, frequent equipment assembly and dismantling, and the need to move from site to site. The GT6000 Mobilis delivers real-time results, providing immediate feedback on the progress and validity of QAL2 tests. Users can monitor humidity levels and receive automatic notifications if any unpredictable events occur during the measurement process. Additionally, preliminary information regarding the results can be shared with users directly after (or even during) the campaign, enhancing communication and efficiency. — *Gasmet Technologies Oy, Vantaa, Finland*
www.gasmet.com ■

Scott Jenkins

Milling for Particle Size Control

Department Editor: Scott Jenkins

Milling is commonly used for particle-size reduction and control of particle-size distribution (PSD) for crystalline solids. Mills are effective for generating consistent solids properties, through size reduction and surface-modification mechanisms [*1*]. This one-page reference outlines the mechanical forces involved in size reduction and the important material properties for selecting milling equipment.

Forces for size reduction

In comminution, solids are fractured by mechanical force delivered to particles by the milling machine. This is achieved in a myriad of ways, depending on the mill type. Seven different types of stresses can be imparted to achieve size reduction, as listed below [*2*]:

1. Compression between two rigid surfaces
2. Compression between two rigid surfaces and against an adjacent bed of solids
3. Shearing (tearing, cutting, shredding and cleaving) mechanically
4. Shearing forces due to surrounding media
5. High-velocity impact against a rigid surface (particle impacting a stationary surface or a moving surface impacting a particle)
6. Particle-particle impact causing breakage and shattering
7. Abrasion during particle-wall and particle-particle impacts

Desired performance of size reduction can be achieved by matching the machine design with particle properties and mode of operation.

Key material properties

The following properties of the material must be evaluated for suitable selection of equipment and to understand its size-reduction behavior.

- PSD in the feed material
- Particle shape
- Bulk density
- Flowability, cohesiveness or adhesiveness
- Corrosivity and composition
- Moisture content
- Hardness, brittleness, friability
- Toxicity
- Abrasiveness
- Shock sensitivity or explosivity
- Elasticity, plasticity ductility
- Dust-explosion characteristics
- Temperature sensitivity — degradation, stickiness, phase change
- Fibrous morphology
- Oil or fat content, especially those released during grinding
- Reactivity or release of gases
- Stickiness

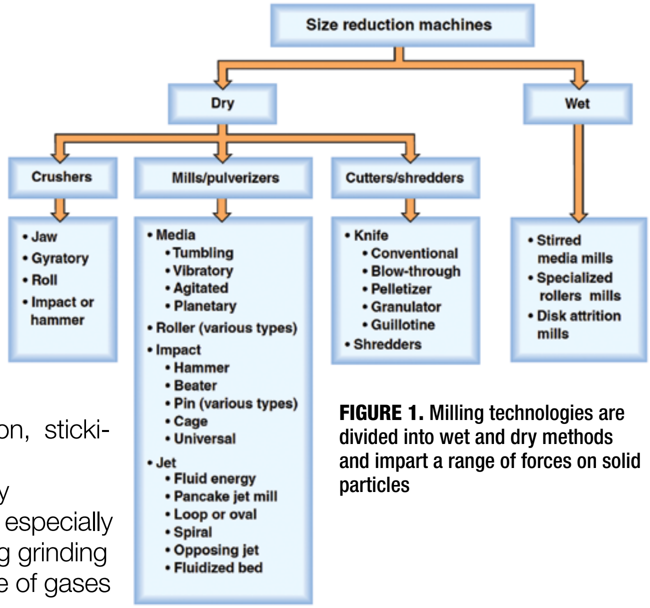


FIGURE 1. Milling technologies are divided into wet and dry methods and impart a range of forces on solid particles

Milling equipment

The choice of milling equipment for an application depends on the performance capabilities relative to the properties of the feed material, as well as constraints of the mill type.

Broadly, mills can be separated into wet and dry mills, and these two categories are each further subdivided by how comminution is achieved, such as rotor-stator mills, jet mills, pin mills, hammer mills, media (ball) mills and cavitation mills. Wet mills use liquid as their working fluid, whereas dry mills use gas. Figure 1 (adapted from Ref. 2) shows how various milling techniques are categorized. Each type of mill is characterized by an energy input mechanism.

Effects on solids properties

Milling processes have several general effects on solid particles. Several are outlined here:

Particle size reduction. The mechanical forces imparted by the mill reduce particle size.

Particle-size distribution changes. Generally, milling results in narrower PSDs, and is intended to provide normalization (a similar size distribution of product is obtained for various size distributions of feed materials). Theoretically, a milled product is predicted to have a log-normal or Weibull distribution, a probability distribution best fit by a function with two or more parameters [*1*]. The function is related to the probability of a particle fracturing and the nature of the fragment as a function of its original size. Practically speaking, this means that milling does not typically give symmetrical Gaussian distributions. Skewness and tails are common.

Increased surface area. Milling generally increases total surface area as solid particles are broken.

Surface property changes. Particle surfaces are altered as solids are milled, and this can affect how particles behave with regard to mixing, compacting, dissolving, aerosolizing and interacting with moisture.

Particle shape changes. Milling also impacts particle shape, or morphology, particularly for high-aspect-ratio "needle-" or "rod-"type particles. The comminution fracture mechanism often operates along the length of these crystals, effectively chopping them along the length scale into shapes with lower aspect ratios. This breakage gives rise to consequent change in the physical attributes, such as bulk density, as well as formulation behavior, such as flow properties. ■

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Chemical Recycling is Essential for Plastics Circularity, but Faces Challenges

Environmental imperatives drive the development of technologies for the chemical recycling of plastic waste, but significant hurdles – including economic viability, collection logistics and feedstock complexity – need to be addressed for chemical recycling to have a larger impact

Plastic waste continues to be a major global environmental issue. While mechanical recycling, where plastic waste is ground up and remelted, remains the most prominent form of plastics recycling, its limitations (material degradation, contamination and performance) prevent it from enabling real plastics circularity. The field of chemical recycling of plastics, which aims to break down polymers into starting materials that are chemically equivalent to petroleum-derived feedstock, is a fast-evolving area that is critical for achieving true plastics circularity.

It is generally envisioned that chemical recycling will not replace mechanical recycling, but rather, will complement it (Figure 1). In cases where mechanical recycling can be effective, it will be used preferentially, since its costs are lower. However, because mechanical recycling cannot be used indefinitely, and is only effective with uncontaminated, single-component waste streams, chemical recycling technologies will continue to have wide-ranging opportunities.

"We anticipate strong growth in the chemical recycling industry over the next decade, despite a host of challenges that have led to slower-than-envisioned progress on plant development and some project failures," says James Kennedy, an analyst with market research firm IDTechEx (Cambridge, U.K.; www.idtechex.com). "It's definitely a mixed picture within chemical recycling, with a variety of ups and downs, and different stories playing out among the different technologies," he comments.

Economic viability

The field of chemical recycling can be divided into four general technology categories: pyrolysis, solvolysis, thermochemical processing and dissolution. Because of three factors — the size and complexity of the plastic waste issue, the diversity of polymer types and formulations, and the growing demand for recycled plastics — it is likely that most or all chemical recycling approaches will have opportunities in certain situations. And chemical recycling will exist as part of a mosaic of potential solutions for addressing plastic waste, including other external efforts, such as reducing plastic usage, designing for recyclability and incorporating alternative bio-based materials.

Within each chemical recycling technology category, there are significant efforts to reach technoeconomic viability. "The main concern right now overall is the cost of the technology," says Marcian Lee, an analyst with Lux Research (Boston, Mass.; www.luxresearch.com). "It has to make good financial sense for companies to invest in [chemical recycling] technologies," he says.

"Consumers will often say they would pay a 'green premium' for purchasing products made from recycled materials, but at the time of actual purchases, the follow-through action often fails to back up the sentiment," Lee says.

FIGURE 1. Mechanical and chemical recycling approaches are expected to be used complementarily for waste plastics

Current price premiums for chemically recycled polyethylene terephthalate (PET) are estimated at two to three times the costs for petroleum-derived virgin plastics, Lee says. "For mechanically recycled plastics, I commonly hear a 30% premium is the ballpark maximum that most companies will pay for."

"If left strictly to a free market, achieving plastics circularity through recycling is an extremely daunting prospect right now," Lee says. "Regulatory mandates for utilizing recycled material are likely needed to spur the industry forward." Chemical manufacturers are looking for government regulatory agencies to take a clear legislative stance and provide regulatory guidance. The details of these policies will have a large impact on how the chemical recycling industry will develop, Lee explains. (For more, see box, p. 20).

Pyrolysis prospects

In terms of announced capacity, the largest share of advanced recycling falls under the umbrella of pyrolysis, a recycling approach in which waste plastics are exposed to high heat in an inert (oxygen-free) environment to break down polymer chains into naphtha substitute that can serve as feedstock for other products or fuels. This technology class has received significant investment from many large companies in the oil-and-gas sector, because the pyrolysis oil resulting from processing plastic waste in this way can be integrated into existing petroleum refining and petrochemical assets. TotalEnergies, Shell, ExxonMobil, BP, Chevron Phillips Chemical and others are among the oil-and-gas majors investing in pyrolysis technology.

Lee, from Lux Research, says that the period between 2024 and 2025 is a key inflection point for pyrolysis, "where we may see 1 million tons/yr of completed global pyrolysis capacity — a sign of the technology's commercial maturity." However, Lee has also observed that only half of the announced pyrolysis capacity has been realized thus far. For example, the Brightmark recycling plant in Ashley, Ind., which runs a pyrolysis process, has faced significant delays in reaching full capacity. And in July, Shell plc, which had been among the companies expressing optimism about pyrolysis, announced that it is scaling back its goals for pyrolysis recycling.

And scrutiny of pyrolysis processes is ongoing, partly because the pyrolysis products can be used to make fuels, rather than new plastic, raising the question of what actually counts as recycling. In September, California attorney general Rob Bonta filed a lawsuit against ExxonMobil after a two-year investigation, charging that the company has been "deceiving the public" about the potential of plastics recycling. Pyrolysis processes are at the center of the lawsuit, which alleges a wide gap between the amount of recycled content the company says it incorporates into its products, and what is actually contained.

A critical regulatory question for pyrolysis projects is whether plastics derived from pyrolysis oil will count as recycled content. If governments don't allow it, there is little or no incentive to use pyrolysis oil over traditional crude oil.

Stepping up the pyrolysis game

"Pyrolysis is a viable technology for chemical recycling of polyolefins and mixed plastic streams, but its problem is that it is very imprecise," explains Marcian Lee from Lux Research. "It's difficult to get high yields of propylene from waste polypropylene, for example, and instead, many pyrolysis processes generate a wide range of hydrocarbons of random lengths when breaking the polymer." Products range from CH_4 to C35+ waxes. At large scales, achieving precise breakage is a significant challenge, but would be a distinct advantage, he says.

"Some thermochemical recycling methods can be thought of as 'next-generation pyrolysis,' where polymer chains are broken down in a more precise and targeted way," Lee says.

Strategies including the use of catalysts to narrow the range of products, are being developed. These projects, mostly in the pilot stage now, "require precise control of temperature, because if that parameter varies, you start to get side reactions and more undesired species," says Lee. While catalysts may improve product specificity, they also add complexity and cost.

In a recent example involving catalysis, LyondellBasell (Rotterdam, the Netherlands; www.lyondellbasell.com) started construction in September on its first advanced recycling plant at its Wesseling, Germany site (Figure 2). The project focuses on LyondellBasell's proprietary MoReTec technology, a catalytic pyrolysis process developed with the Karlsruhe Institute of Technology (KIT; Karlsruhe, Germany; www.kit.edu) that converts pre-treated, mixed-waste plastic into raw materials to produce new plastic polymers. The incorporation of catalysis into the process allows lower operating temperatures than conventional pyrolysis, and allows a greater degree of selectivity of the chemical reactions. Rather than a range of mixed hydrocarbons,

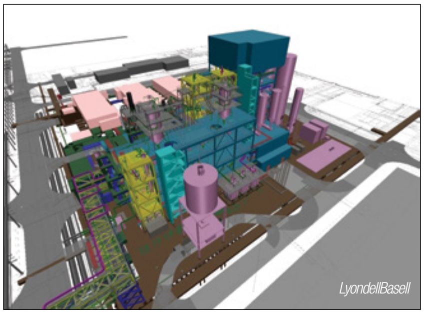

FIGURE 2. LyondellBasell started construction in September on a catalytic pyrolysis unit at its site in Wesseling, Germany

MoReTec produces virgin-quality polymer feedstocks that can be directly reintegrated into new plastic production, the company says. Anticipated startup for the new unit is in 2026, and other facilities are planned, according to the company.

Another example of a "next-gen" thermal separation process comes from Carbon Rivers (Knoxville, Tenn.; www.carbonrivers.com), a company that has developed a mechanical and thermal process for downsizing and separating polymer composite materials, such as glass- or carbon-fiber-reinforced polymers. Carbon Rivers chief strategy officer David Morgan says the advanced materials engineering innovation firm makes various specialty materials, but is also advancing a process to efficiently separate polymers from glass fibers in composite materials used for wind turbine blades, marine vessels, aerospace, building materials and automobiles.

The company has developed an unconventional modified pyrolysis process to separate organic polymer resins from the glass fibers without degrading the glass. "We have a low-temperature thermolysis step that cracks the polymers, and a circular scheme that recovers the glass fibers intact, so they can be reused in other composites," says Morgan.

To make the process work, Carbon Rivers had to find ways to minimize glass degradation during the process and identify the correct temperature to crack the polymers to allow for the separation. Then they apply a sizing chemistry in order to use the recycled glass fiber (rGF).

The company is currently in the engineering design stages for a commercial-scale facility in Texas for

RECYCLING LOGISTICS AND RECYCLED MATERIAL MANDATES

A massive challenge for plastics circularity is establishing a network of infrastructure for collecting used materials and transporting them to processing sites, and then getting the recycled material back into the production system. Industry Consortia may have an impact in this area. The Global Impact Coalition (GIC; Geneva, Switzerland; www.globalimpactcoalition) is a spinoff from the World Economic Forum aimed at advancing net zero and circularity in the chemical sector at a faster rate. GIC director Charlie Tan says "The GIC at its heart is an enabling and accelerator platform for bringing new ways of collaboration to market faster, also through value chain integrations and unconventional partnerships."

"To drive new business models to final approval, [the industry] needs a justifiable sustainability and commercial case," Tan states, adding, "we need platforms to aggregate demand for green products and financing approaches to leverage and allocate both public and private capital for many aspects of sustainability strategy, including in the field of recycling."

Among the several projects being undertaken by the GIC is a pyrolysis-oil project where the GIC is setting up a business intelligence platform facilitating the scaleup of pyrolysis plants, and fostering utilization of pyrolysis oil by the chemical industry. "We want to connect the various actors in the chain, including investors, with companies who want to start up pyrolysis plants, and show investors that there is a market for pyrolysis oil to build trust in the industry," Tan says. "There's a need for more of a formal and transparent compounding and alignment of standards, definitions, and terminology."

The GIC is also leading a project on automotive plastics circularity, aimed at improving closed-loop plastic recycling rates, connecting supply-chain players and selecting sorting sites. The GIC is in the process of developing a pilot project to evaluate the idea.

To a significant extent, the speed of deployment and expansion of chemical recycling facilities may hinge on government policies aimed at fostering investment in recycling-technology development projects. For example, the European Green Deal (commission.europa.eu), enacted in 2020, includes ambitious targets for incorporating recycled materials into plastic packaging. The U.K., Canada and Australia also have similar legislation in place. In the U.S., California passed a law on the incorporation of recycled plastic in 2020, but no country-wide legislation exists. The Accelerating a Circular Economy for Plastics and Recycling Innovation Act of 2024 is a bill under consideration in the U.S. House of Representatives. The American Chemistry Council (Washington, D.C.; www.americanchemistry.com) has expressed support for the bill, noting that it would help modernize recycling infrastructure and promote investment. "This bill would bring about transformational change to how we recycle plastics in this country, while creating regulatory certainty for businesses to tackle these important challenges," ACC President and CEO Chris Jahn said. ❐

processing post-industrial and post-consumer composites and developing a novel continuous recycled-glass-fiber filament. Construction will begin in Q2 2025, Morgan says.

The Carbon Rivers process is suitable for epoxy, polyurethane, polyester, vinyl ester and Elium, and could be used to recycle wind turbine blades and marine hulls.

PET solvolysis ups and downs

The most technologically mature chemical recycling technique may be the use of solvolysis for depolymerization of PET, a common polyester used for beverage bottles and many other products. Solvolysis, a recycling approach in which ethylene glycol (glycolysis), methanol (methanolysis) or other chemicals are used to cleave polymer linkages in waste plastic, works for condensation polymers (including polyesters, polycarbonate, polyamides), but not for mixed plastic streams containing polyolefins.

Earlier this year, Eastman Chemical Co. (Kingsport, Tenn.; www.eastman.com) started the world's largest molecular recycling facility at its Kingsport site using a methanolysis process (Figure 3), and announced further investments in other methanolysis facilities in Longview, Tex. and Normandy, France. In October, Eastman said work on the Texas project remains on track. The project features deployment of thermal heat batteries and onsite solar power, along with the recycling technology. Combined, the facility can achieve up to 70% reduced carbon emissions for recycling PET. "We can take polyester waste that mechanical recyclers cannot handle today, such as colored and opaque PET, clamshells, polyester carpet and textile fibers and more," an Eastman spokesperson said.

For the project in France, the priorities remain "securing customer offtake contracts and value engineering," Eastman says. "We remain confident in the need for this and other plants, but continue to evaluate the optimal timing of the project."

Some solvolysis recycling approaches use ethylene glycol (EG) as the reagent. SABIC (Riyadh, Saudi Arabia; www.sabic.com) is using a glycolysis process to depolymerize PET waste (mostly single-use water bottles) into monomers and oligomers. These are then dissolved and combined with 1,4-butanediol to upcycle the material into polybutylene terephthalate (PBT). PBT resins containing recycled PET have a smaller environmental footprint, in terms of cumulative energy demand and global warming potential, than virgin PET resin, SABIC says. PBT is used for products requiring enhanced properties and more durability, like electronic wire coatings.

Another solvolysis project, however, recently ran into trouble. The company Ioniqa (Eindhoven, the Netherlands; ioniqa.com) is developing a solvolysis process using EG and a proprietary catalyst to make virgin-quality materials from PET waste. Ioniqa had established a demonstration plant in Geleen, the Netherlands, but in October, the company announced it is seeking bankruptcy protection, citing higher costs than petroleum-derived plastics and an underdeveloped supply chain for plastic recycling. "The advanced recycling sector is challenged by the low cost of virgin plastics derived from fossil oil and a plastic recycling supply chain still in development. Furthermore, the implementation of regulated mandatory standards for meaningful recycling levels are too far out into the future," Ioniqa says. Combined, these factors render large-scale deployment of Ioniqa's technology "economically unfeasible," the company says.

Dissolution

Plastics recycling processes based on dissolution technology aim to address a major recycling challenge: many plastic products contain multiple materials, such as packaging films with layers of polyethylene (PE) and the oxygen barrier ethylene vinyl alcohol (EVOH), which complicates any efforts to recycle them. Dissolution approaches are based on se-

FIGURE 3. The chemical recycling facility at Eastman's Kingsport, Tenn. site began producing recycled material from PET waste earlier this year

lective dissolution of one layer with a solvent mix that does not dissolve the other layers. The undissolved portion is filtered out and the dissolved polymer is precipitated with low temperatures or antisolvents.

Marcian Lee says: "Dissolution has a big role to play in engineered plastics, because it is tolerant of contaminants. While it is hard to get to food-contact-grade material with dissolution technologies, it is not hindered by contaminants as long as they don't dissolve in the solvent, which are generally trade secrets."

One company working on scaling up a dissolution process is APK AG (Merseberg, Germany; www.apk.group). The company's NewCycling process produces low-density PE granules from mixed plastic packaging waste by selectively dissolving PE and separating it from other polymers, additives and contaminants in the waste stream. APK says its recycling process lowers CO_2 production by 66% compared to new plastic. The company has plans to isolate other polymers as well. In October, LyondellBasell completed its acquisition of APK.

Another example of a dissolution process is the solvent-targeted recovery and precipitation (STRAP) process, developed by scientists at the University of Wisconsin-Madison (www.wisc.edu) led by George Huber. Construction of a pilot plant for a continuous STRAP process was begun last year at the Michigan Technical University (www.mtu.edu), in a collaboration led by MTU professor Ezra Bar-Ziv.

Enzymatic depolymerization

Another approach to depolymerization utilizes enzymes to cleave the polymer bonds in plastic waste. This technology, sometimes included under the solvolysis umbrella, is somewhat less mature than some other chemical recycling technologies, but it is attractive because it requires less energy than many other approaches. Thus far, enzymatic depolymerization has been developed with a focus on PET, but theoretically, it could be used for other polymers. A leader in this area is Carbios (St. Beauzire, France; www.carbios.fr). In May 2024, Carbios broke ground on the world's first PET biorecycling plant based on enzymatic depolymerization in Longlaville, France. The plant will have a processing capacity of 50,000 tons/yr of prepared waste when operating at full capacity, the company says, and products are expected to be delivered in 2026. It will handle multilayered, colored and opaque polyester packaging waste and polyester textile waste.

Thermochemical approaches

Because many waste streams consist of mixed plastics with contaminants and additives, there is keen interest in recycling processes that can accommodate a broader range of feedstocks. One approach is using supercritical water to break down plastic waste. Mura Technology (London, U.K.; www.muratechnology.com) developed Hydro-PRT, a process that uses water above its critical point to produce fossil-equivalent oils from mixed, multi-layered flexible and rigid plastic waste for the petrochemicals industry to create virgin-grade plastics.

The company says its first commercial-scale Hydro-PRT plant, in Teesside, U.K., will become the world's largest advanced recycling plant when it commences operations later this year. Two further plants being built under license with partners in South Korea and Japan, are expected to come online next year.

The application of microwaves to as a method of energy transfer has emerged as an alternative approach to processing plastic waste streams. Startups such as Pyrowave Inc. (Montreal, Que.; www.pyrowave.com) and Microwave Solutions (Riehen, Switzerland; www.microwavesolutions.ch) are among those pursuing the use of electrically powered microwaves to replace thermal methods for plastics recycling.

Microwave Chemical Co. Ltd. (MWCC; Osaka, Japan; www.mwcc.jp) is also pursuing this, and has partnered with Asahi Kasei (Tokyo; www.asahi-kasei.com) to scale up its technology, known as the PlaWave platform. MWCC and Asahi Kasei plan to begin constructing a pilot plant using microwaves to depolymerize polyamide-66 (nylon) in 2025. The partnership envisions expanding the approach to other plastic types also.

MWCC's Yuri Katoda says "Microwaves serve as a method of energy transfer, rather than initiating a specific chemical reaction . . . Each material has its own unique microwave absorption capability. And by leveraging these characteristics, we are engineering optimal depolymerization conditions based on microwave heat transfer principles."

In the case of PA-66 recycling, the microwave process directly generates the monomers hexamethylenediamine (HMD) and adipic acid (ADA) at high yield with low energy consumption, Katoda says. Advantages of microwaves include precise temperature control, smaller facility footprint and decarbonization (use of renewable energy possible).

"Our chemical recycling technology is based on the microwave absorption capabilities of different plastics," Katoda explains, "so we are basically prepared to adapt our technology to any type of plastic." MWCC aims to build a commercial plant within the next several years, Katoda says.

Another recycling company employing microwaves is GR3N S.A. (Lugano, Switzerland; blog.gr3n-recycling.com). GR3N has developed microwave-assisted depolymerization (MADE) to break down PET into its monomers and create new PET pellets with quality comparable to virgin plastic. The technology combines microwaves with alkaline hydrolysis in a way that tolerates higher levels of impurities than existing methods, the company says. The company is building a facility in Spain to produce 40,000 tons/yr of "virgin-like PET." ■

Scott Jenkins

Selecting Valves for Hydrogen Service

With hydrogen's evolution into an alternative fuel requiring precise production and storage, selecting the right valves has never been more important

Chuck Hayes
Swagelok Company

IN BRIEF

Hydrogen shows great promise in the search for alternative fuels. Handling hydrogen safely and reliably, from generation to end use, is the key to reaching its fullest potential as a zero-emission fuel source in a wide variety of applications.

As hydrogen as a fuel source gains traction, the industry must build systems that can produce and store it properly, including leak-tight systems constructed from the highest-quality materials (Figure 1). Only then can the system be counted on to last for years or even decades of safe operation. Choosing the right system components — from valves to fittings to tubing — is paramount, because some materials cannot withstand the particular stressors involved in hydrogen distribution systems. And when the materials are not right for an application, safety may be compromised.

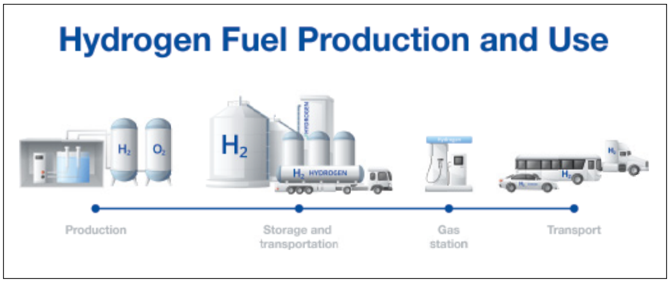

FIGURE 1. Components used in hydrogen service must deliver long-term leak-tight performance from production operations to storage and transportation applications

Hydrogen-specific challenges

Hydrogen molecules are challenging to contain because they are so small and volatile. Each connection point within a hydrogen system cannot leak, because even the smallest leaks pose safety risks to end users. This would be of particular concern, for example, when refueling vehicles. Any system leak is also wasteful.

Hydrogen molecules (shown as H_2, blue, in Figure 2) can dissociate to atomic hydrogen (shown as H, red, in Figure 2) and penetrate a metal. Hydrogen atoms accumulate at stress concentrations, such as at the tips of cracks or along microstructural features like grain boundaries, inclusions or precipitates. In certain cases, atomic hydrogen can reform as diatomic hydrogen.

One of the biggest problems posed by tiny hydrogen molecules is their ability to diffuse into some lower-quality stainless steels, causing a phenomenon known as hydrogen embrittlement. This characteristic can cause components to weaken over time as cracks occur and lead to system failure (see the "How to Avoid Hydrogen Embrittlement" sidebar on p. 24).

Choosing high-performance valves

Even under ideal conditions, hydrogen valves undergo challenges to their integrity and performance. As system designers decide which valves are most appropriate for their application, they must consider the following parameters:

- *Pressures.* To achieve the desired density, hydrogen gas must be stored at 350–

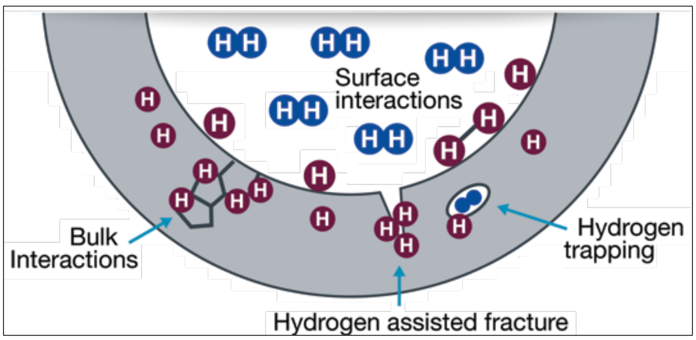

FIGURE 2. When hydrogen atoms embed themselves in system components, it can lead to fractures and fatigue in the components, which could produce premature failures

700 bars for various applications, including plant operations and on-vehicle systems.

- *Stress and vibration.* Any operational stresses and vibrations a hydrogen system encounters have the potential to cause fitting connections to work themselves loose and cause leaks. Hydrogen fuel systems must be able to withstand those stresses and remain tightened and leak-free.
- *Safety.* The use of hydrogen carries numerous potential risks. Systems must be designed to mitigate threats related to gas leakage, temperature increases, and hydrogen embrittlement. In addition, the average consumer must be able to safely operate a refueling station.
- *Maintenance.* It should also be easy to remake leak-tight joints when they need to be serviced for any system, including at the production, storage, transportation and usage level.

These four performance parameters cannot be sacrificed. Each selected valve should provide leak-tight performance at connection, shutoff and regulation points. System designers should then specify valves with the particular challenges and necessary operating conditions of hydrogen applications top of mind.

Those valves may include any of the following types:

Hydrogen ball valves. Hydrogen systems often contain ball valves, which start and stop gas flows from one direction to the next (Figure 3). Proper hydrogen ball valves should include wear-resistant stem-seal designs. For example, it may make sense to specify a trunnion-style ball valve with a direct-load design, which provides leak-tight performance each time it is activated and shut off.

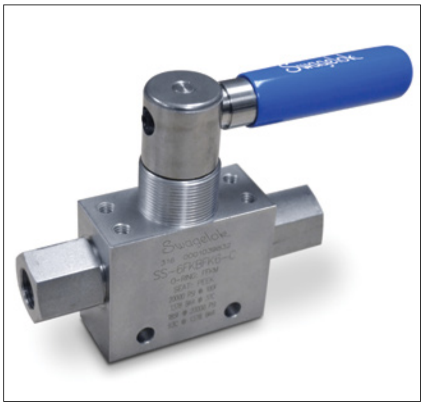

FIGURE 3. Ball valves for hydrogen applications should have highly wear-resistant stem seals for safety

Another option is a bottom-loaded stem design, which can be safer than other valve designs, because such valves are less likely to blow out their stems. Hydrogen ball valves may also offer two- or three-way functionality, different mounting options, and a range of flow coefficients to meet varying system needs. Regardless of the specific valve chosen, always look for good compatibility with fittings that are designed specifically for hydrogen applications. A qualified valve supplier can help guide your selection.

Hydrogen needle valves. When fluid flows require fine adjustments, needle valves are often the answer (Figure 4). However, other factors influence whether needle valves are right for specific hydrogen applications. First, they are often made completely out of metal, meaning it takes significant force to open and close them. The amount of force necessary might eventually deform the needle and seat, rendering it incapable of operating properly and presenting a potential safety issue. Additionally, large air actuators are typically used to open and close the valves, which can take up to two minutes to complete.

Given the above factors, it is evident that hydrogen needle valves must be made from the strongest possible steel. High-quality 316 stainless steel, for example, resists deformation over time and can withstand the pressures exerted on valves in hydrogen applications (usually 350–700 bars). The composition of that steel is especially important so it can better resist the challenges related to hydrogen embrittlement (see the sidebar for details).

Not all needle valves will have the required pressure rating to handle common hydrogen applications, so when selecting, be sure to choose valves that are qualified for elevated working pressures. In addition, ensure the chosen needle valves are compatible with any other hydrogen-qualified components used in the system.

FIGURE 4. Hydrogen needle valves should be made from high-quality 316 stainless steel

FIGURE 5. Ball check valves are used to control excess backflow in hydrogen compressors for refueling systems

Hydrogen check valves. Finally, check valves are essential to properly functioning hydrogen compressors in refueling systems (Figure 5). For example, most check valves use strain-hardened springs, which can be unusually susceptible to hydrogen embrittlement. In contrast, using springs made from high-quality 316 stainless steel reduces the chances of embrittlement weakening the springs. Another challenge is the often severe temperature and pressure changes common to hydrogen applications. These severe changes can damage the elastomer seals in valves. Ideally, most hydrogen compressors would use ball check valves over other non-specific ones.

Just like with the other two types of valves, material integrity and compatibility with other hydrogen components are important for check valves.

HOW TO AVOID HYDROGEN EMBRITTLEMENT

Containing and transferring hydrogen presents unique challenges due to its atoms being among the smallest found in nature. Complicating things further, hydrogen needs to be handled in both liquid and gaseous forms. Hydrogen liquifies at a very low temperature of –252.9°C (–423°F) and is about 140 times denser as a liquid compared to its gaseous form. Transporting and storing hydrogen as a liquid is more efficient, but at its point of use, hydrogen is a gas, so it will need to be converted from liquid to gas.

As a result of the conditions required for these phase changes, two phenomena can impact metals used in hydrogen systems for tubing, valves, fittings and other components.

Low-temperature embrittlement refers to a reduction in ductility, toughness, or fatigue and fracture resistance, as the temperature is decreased. Austenitic stainless steels suffer only minor, low-temperature embrittlement, while ferritic steels (low-alloy steels and ferritic stainless steels) are more susceptible. For this reason, austenitic stainless steels are the gold standard for liquid hydrogen systems.

Hydrogen embrittlement causes a reduction in fatigue and fracture resistance of a metal. Very high-strength materials experience more severe hydrogen embrittlement. Austenitic stainless steels are characterized by their face centered cubic (FCC) crystal structure, moderate strength and naturally high ductility. And while they are generally more compatible with hydrogen than many other metals, not all resist hydrogen embrittlement equally.

Quality stainless steel matters

High-quality stainless steels containing elevated levels of nickel have been shown to be better suited to handle hydrogen — particularly over a long service life. Higher concentrations of chromium in the steel can also help to better defend against common corrosion (Figure 10).

ASTM International (www.astm.org) requires a minimum of 10% nickel in 316 stainless-steel formulations, but 316 stainless steel with a minimum of 12% nickel is better for the unique challenges posed by hydrogen. Nickel content helps stabilize the microstructure of stainless steel, enabling it to be more resistant to hydrogen embrittlement. In testing conducted by Swagelok, the company has found the effect of hydrogen embrittlement on the tensile ductility of 316 stainless steel with 12% nickel to be minor.

While 316 stainless steel with high nickel content is generally a compelling choice for hydrogen system construction, there may be situations in which performance criteria for a specific application, such as a need to prioritize material strength or corrosion resistance, make another material choice a good option. Proper system design and maintenance can help deter embrittlement in these cases.

It can be challenging to discern which materials are optimal for different fluid handling applications, particularly in the burgeoning hydrogen industry. But it is important to get it right. There are long-term implications for specifying materials for hydrogen systems. Most importantly, the wrong choices have the potential to damage hydrogen's reputation as a reliable and viable fuel source for a cleaner future. Seek out suppliers that can demonstrate a thorough understanding of materials science and have developed products that have been successfully used in hydrogen applications. ❐

How fittings fit

Selecting the most appropriate valve types, materials and configurations for hydrogen applications is not the only consideration when building a well-functioning hydrogen production and storage system. Installing the right fittings to connect those valves is just as important.

Since hydrogen is such a volatile gas, it is crucial to demand uncompromising fitting performance. Each connection in a hydrogen production and storage system is a potential leak point, and ensuring the fittings work effectively with the valves is essential. Although traditional cone and thread fittings are typically used for these applications, other options exist that may be more appropriate for hydrogen systems.

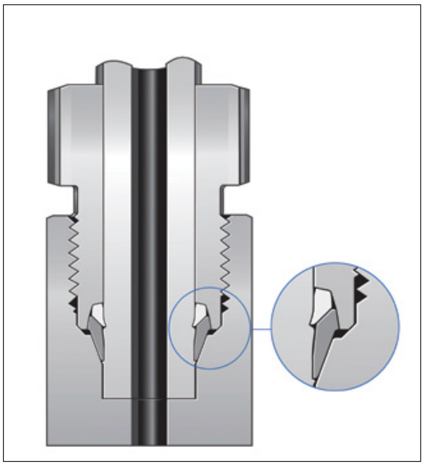

FIGURE 6. The two ferrules in this fitting design provide a hinging and colleting action that securely grips the tube. The hardened front ferrule (dark gray) enables the fitting to physically bite into the tubing. The back ferrule (light gray) allows for a slight amount of movement in the fitting while maintaining grip and force

FIGURE 7. Fittings with preassembled cartridges can reduce installation times by 80%

To function effectively in hydrogen systems, fittings must have the following characteristics of seal tightness, grip strength and simple installation:

Seal tightness. The most effective fittings for hydrogen containment have two long lines of contact across longer sealing surfaces. The contact surfaces should be at an angle to provide optimized stress levels, which will allow the seal to stay tight under most operating conditions. Certain styles of two-ferrule tube fittings can deliver this kind of seal integrity.

Grip strength. A colleted mechanical grip using two ferrules is ideal for hydrogen fittings to create a robust grip (Figure 6). A hardened front ferrule can enable the fitting to physically bite into the tubing, creating a very high pressure rating. Meanwhile, a unique back ferrule design allows for a slight amount of movement in the fitting (called "spring back") while maintaining grip and force.

Simple installation. Some available mechanical grip fittings are designed with preassembled cartridges (Figure 7). This enables installers to use common tools and requires minimal training to achieve rapid, error-proof assembly. When compared to traditional cone and thread fittings, which have traditionally been used in hydrogen production and storage systems, preassembled cartridges are much easier to install (Figure 8).

While there are a variety of compression tube fittings and other styles that may be applicable to hydrogen systems, very few are designed to satisfy the many unique performance demands hydrogen applications require.

FIGURE 8. Traditional cone-and-thread fittings require significant machining and are not designed for ease of installation

FIGURE 9. Danish company Everfuel uses an array of fittings and valves rated for hydrogen services to operate electrolyzers as part of the company's pioneering HySynergy PtX plant

Hydrogen service in action

Ball valves, needle valves, and fittings rated for hydrogen service are what helps Denmark's HySynergy project tick. The 20-megawatt Power-to-X (PtX) facility built by Everfuel to test the viability of large-scale hydrogen dispensing and storage recently completed its first phase (Figure 9).

The facility is hoping to bring the promise of green hydrogen to fruition. Upon completion of Phase II of the project, Denmark is poised to reduce carbon emissions equivalent to 11% of what comes from the Danish land-based transport sector. Upon completion of Phase III, which is targeted for 2030, the project will provide further carbon footprint reductions, contributing significantly to the country's 70% carbon dioxide reduction target.

Top-rated components make up the fluid systems that compress and contain highly combustible hydrogen in a leak-tight environment at the HySynergy PtX plant. These specialty fittings and ball and needle valves feature a higher nickel content to help prevent hydrogen embrittlement (Figure 10). Their leak-tight performance is a testament to the careful attention to material properties in their makeup, as well as their adherence to the four required performance parameters for handling the pressures, stress and vibration found in hydrogen service, while maintaining safety and enabling simplified maintenance.

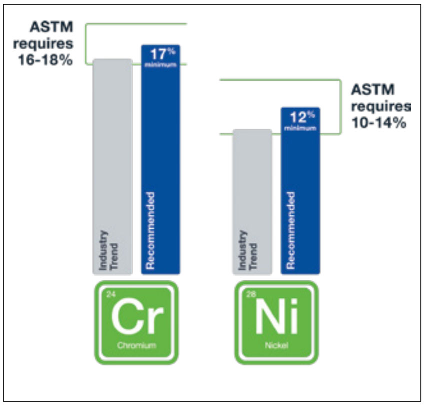

FIGURE 10. Stainless steels with higher nickel content provide much more protection from hydrogen embrittlement than lower-nickel stainless steels

Why compatibility matters

For all the valves used in hydrogen applications, compatibility with other components is key. It is important to ensure all components are designed specifically for hydrogen use so they work together in harmony to keep everyone safe throughout the process.

The long-term viability of hydrogen as an alternative to fossil fuels will depend on safe, reliable and durable production and storage systems. Selecting and specifying the right components for critical systems can help achieve these goals. Using the proper components, including well-designed, hydrogen-specific valves, will help ensure hydrogen's leading place in the alternative fuel market. ■

Edited by Dorothy Lozowski

Acknowledgement

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Author

Chuck Hayes is a 30-year veteran of Swagelok Company (Solon, Ohio, USA; www.swagelok.com). He has spent the last 25 years developing a wide range of fluid system products and the past 20 years focused exclusively on fitting technology for alternative fuel applications. Today, he concentrates most of his time on the development of hydrogen mobility solutions for both refueling infrastructure and on-vehicle applications. Chuck currently holds 7 patents in the U.S. and numerous patents internationally.

Rotary Valves Can Prevent Stem Seal Woes

Consider the potential for stem seal leakage when selecting a valve

Peter Jessee
Valin Corp.

Experienced process control engineers follow familiar, time-tested steps when presented with a new system to design and specify. Selecting a control valve for a process always requires the same information: collection of the process conditions, calculating required capacity and determining the materials that will survive in the process stream. But some process streams present more challenges than others.

Challenging gases and liquids

Some processes resist staying within the confines of the piping system. Gases with small molecules, like hydrogen and helium, present many difficulties, such as being able to permeate through the actual metallic structure of diaphragms and thin foils, as well as sealing mechanisms like valve stem packing (for more on hydrogen applications, see Part 1 of this Feature Report, pp. 22–25).

However, even some common liquids can provide a difficult challenge when specifying valves. Heat transfer oil is notorious for leaking through seals, packing and threaded connections. Glycol is another problematic liquid that frequently finds its way through process seals. Petroleum refineries and chemical plants have many intermediate and end products that present similar concerns. These kinds of fluids can be challenging enough if they are only causing unsightly drips, stained insulation or messy floors beneath the pipes. But what if the process fluid is flammable, explosive, poisonous or contributes to climate change?

Valve seals

Engineers that routinely select globe valves for process control often discover the packing that seals around the rising stem struggles to contain many process fluids. This has become a major concern at petroleum refineries and chemical plants, with government agencies focusing on fugitive emissions from valve packing. The "Clean Air Act" in the U.S. and the "Technical Instructions on Air Quality Control" (TA Luft) in Europe have given birth to a compliance industry to provide the regular inspections and emergency maintenance that their regulations require.

A bellows seal on a globe control valve can sometimes provide an effective solution if the process conditions allow. However, these can be very expensive if exotic materials like Monel or Hastelloy are required to be compatible with the process chemistry. The bellows can also add to the height of the valve and increase the required thrust and thus actuator size and price. They also have a finite cycle life, so they may require frequent replacement if the process requires constant modulation or large valve position changes.

Owners that select valves with rotary operation rather than rising stems have found that stem leakage is much less of a concern. With a rising stem valve, the stem seal is forced to resist the effects of the stem drawing process fluid into the process side of the packing on a rising stroke. Environmental debris can also be drawn into the packing on a lowering stroke. This back-and-forth attack frequently results in relatively quick increases in stem-seal fugitive emissions over the maintenance cycle of the valve. With rotary stem valves, the stem seals are always sealing against the same stem surface. External conditions have very little impact on the seal, which can be optimized to deal just with the process conditions.

New types of rotary valves

Fortunately, there have been several new types of rotary valves introduced in the last few decades that offer improved performance in severe-service conditions. Many processes that previously could only be safely handled by globe valves now have rotary options. Rotary valves, like ball and butterfly

FIGURE 1. Process fluid leaked through the packing of this globe valve

FIGURE 2. Changing to this rotary valve eliminated the stem leakage that occurred with a globe valve

valves, have long been used where high flowrates and minimal to moderate pressure drops were the order of the day. However, now there are rotary valves that handle low-valve-flow-coefficient (C_V) requirements, and noise and cavitation-resistant trims are available on several types of rotary stem valves. There are far fewer processes now that must use a globe valve.

Figures 1 and 2 depict one example where a new type of rotary valve provides improved performance over a traditional approach. These pictures show a stark difference in the stem seal performance of a globe (Figure 1) and a rotary (Figure 2) control valve installed in the same process for the same length of time. The owner noticed his globe valves developed "fuzz balls" of process liquid that leaked through the packing and then crystallized. The process fluid in this case is both toxic and flammable, so he looked for another solution. The rotary valve showed no stem leakage over the time it took for this fuzz ball to form.

By changing the type of control valve specified, you may eliminate an operational and maintenance headache for your plant. Remember to consider valves with rotary stem sealing for your problematic processes. ■

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Author

Peter Jessee is a process control application engineer at Valin Corporation (Email: pjessee@valin.com; Website: www.valin.com), a subsidiary of Graybar. He is a licensed professional engineer with over 40 years of experience in control valve technology. Jessee has extensive experience in the refining, chemical, pulp-and-paper and food-processing industries, bringing expertise in optimizing process control and enhancing operational efficiency. With a B.S.M.E., he possesses a solid foundation in the principles of design and systems integration. With a solid background in the design, selection and application of control valves, Jessee has played a critical role in improving system performance and reliability for various chemical and refining applications.

Feature Report

Investigating Decarbonization Strategies for Steam-Cracker Furnaces

Significant sustainability benefits can be gained through optimization in steam-cracking furnaces. The study detailed here shows the specific decarbonization strategies that can help improve energy efficiency and reduce emissions

Ghoncheh Rasouli
KBC (A Yokogawa Company)

IN BRIEF

The chemical process industries (CPI) rely heavily on steam cracking to produce essential olefins — especially ethylene, a key feedstock for polyethylene, polystyrene, polyethylene terephthalate and polyvinylchloride. Over the past decades, there has been significant growth in ethylene demand, with an anticipated increase of approximately 5.58% by 2030, and the associated global polyethylene market is expected to increase 9.6% by 2032 [*1*–*3*]. Steam crackers are the main technology to produce ethylene from light gas or liquid hydrocarbon feedstocks in petrochemical plants (Figure 1). The process is severely endothermic, meaning that conventional steam cracking is the largest energy consumer, and thus also the largest emissions producer, among process units in the CPI, with more than 8% share of the total energy use in these sectors [*4*, *5*]. The energy consumption of ethylene production varies from 15 to 27 GJ/kg of ethylene produced, depending on the feed used in this process [*6*, *7*]. Since energy costs may constitute as much as 70% of the net product cost of an olefin plant, advancing energy efficiency is crucial to reduce energy costs [*4*].

Ethylene production stands among the top three CO_2 emitters in the CPI, with studies indicating that worldwide CO_2 emissions from steam crackers could increase by 33%, from 198.9 million metric tons per year (m.t./yr) to 264 million m.t./yr [*8*]. In conventional crackers, roughly 0.85 to 1.8 m.t. of CO_2 is emitted per metric ton of produced ethylene, depending on the type of feedstock [*9*].

As a result, decarbonization and energy efficiency have become major concerns for olefin producers. While they are compelled to take measures to improve environmental sustainability, most refiners prefer to keep their existing steam cracker configuration and implement energy-optimization and carbon-reduction strategies without any significant changes to their hardware and infrastructure, rather than taking drastic measures to re-design their processes or equipment. Such decarbonization strate-


Shutterstock

FIGURE 1. Steam crackers are nearly ubiquitous across the petroleum refining and petrochemicals sectors. They are also major consumers of energy and contributors to carbon emissions, so the optimization of steam crackers is often a central part of sitewide sustainability initiatives

gies include carbon capture, utilization and storage (CCUS), hydrogen fuel switching, renewable feedstock adoption, steam-cracker enhancement and process optimization.

Process simulation software is a powerful tool to facilitate precise modeling and optimization of complex processes. In this article, a process simulation software with an integrated steam-cracker-furnace model is used to investigate various decarbonization strategies aimed at improving furnace energy efficiency and reducing CO_2 emissions, while providing a comprehensive overview of the decarbonization potential of steam-cracking furnaces.

Decarbonization strategies

There are various approaches for decarbonizing steam crackers — some of these approaches are aligned with net-zero emissions, while others are considered to be near-zero emissions. Several net-zero strategies are illustrated in Figure 2 and discussed further in Refs 8 and 10–12.

Bio-based and recycled plastic waste feedstock. Transitioning toward decarbonization necessitates a fundamental re-evaluation of feedstock. Adopting a circular economy approach, energy consumption and carbon footprint reduction are achieved by substituting conventional fossil fuels with bio-based alternatives, and waste plastics from depolymerization or pyrolysis processes. This approach not only mitigates emissions, but also reduces reliance on finite fossil resources, thereby laying the groundwork for a more sustainable lifecycle [*12–15*].

Thermal efficiency. Remarkable evolution in the energy efficiency of steam-cracker furnaces can be obtained by improving two furnace sections — the firebox and the combustion section. Reduction of energy consumption in the firebox can be achieved by improving firebox radiation efficiency, such as by increasing emissivity, changing coil type and configuration and optimizing the process conditions to increase ethylene yield, including the steam-to-hydrocarbon ratio and coil outlet pressure (COP).

Coil configuration refers to how the heat-exchange coils in the radiation section are arranged within the furnace to facilitate efficient heat transfer. Applying specific coil or tube types, such as ribbed tubes and finned tubes, especially mixing-element radiant tubes (MERT), can improve heat transfer by either increasing the heat-transfer area (cross-sectional area) or heat-transfer coefficient directly. These tube types help increase heat flux through the axial profile and increase run length [*16*, *17*].

Pre-combustion strategies. To reduce the emissions associated with energy-intensive combustion processes, innovative technologies to optimize combustion and fuel switching (changing the ratio of methane to hydrogen) can be investigated, which consequently also will reduce energy consumption. Pre-combustion strategies enhance combustion efficiency by optimizing fuel composition before entering the combustion burner to achieve better fuel and air mixing. This approach aims to maximize combustion efficiency while minimizing emissions from incomplete combustion, improving fuel utilization and consequently, increasing overall furnace efficiency.

Incorporating hydrogen into the fuel mix can lead to efficient combustion, and consequently reduces the carbon footprint, since hydrogen has a high energy content and burns with minimal emission. The hydrogen required for hydrocarbon fuel switching can be obtained through various methods, including water electrolysis, as well as steam methane reforming (SMR) or auto-thermal reforming (ATR) followed by CCUS ("blue" hydrogen). Additionally, hydrogen can be produced by the gasification of fossil- or bio-based fuels into synthesis gas (syngas; a mixture of CO and hydrogen), with subsequent conversion of syngas to hydrogen and CO_2 through the water-gas shift (WGS) reaction. Another source of hydrogen is from the recycled hydrogen-rich byproducts of the olefin plant itself.

Water electrolysis uses electricity to split water molecules into hydro-

TABLE 1. KEY PERFORMANCE INDICATORS (KPIS) FOR STEAM-CRACKER DECARBONIZATION STUDY

Steam cracker KPI	Definition	Unit
Fuelgas consumption rate		m.t./h, m^3/h
Fluegas flowrate		m.t./h, m^3/h
Severity (P/E)	Ratio of propylene to ethylene production rate	wt./.wt.
Fluegas composition (CO_2, O_2)	Molar composition of CO_2 and O_2 in fluegas	mol %
Energy intensity	Total energy consumption per ethylene + propylene production rate. Total energy consumption = Total furnace fuel + Electrical consumption — Steam export	GJ/$m.t._{C2, C3}$
Carbon intensity	CO_2 emission generation per ethylene + propylene production rate	m.t.CO_2/$m.t._{C2, C3}$
Carbon-capture (CC) efficiency	(Fluegas CO_2 rate – Captured CO_2 rate) / Fluegas CO_2 rate	m.t./m.t.
CC energy intensity	Reboiler energy consumption rate per captured CO_2 rate	GJ/m.t. CO_2
Energy savings	Percentage change in energy consumption compared to the base case (negative values indicate a reduction in energy consumption)	%
Emissions reduction	Percentage change in emissions compared to the base case (negative values indicate a reduction in emissions)	%
Margin improvement, CT	Percentage change in margin compared to the base case, taking carbon tax (CT) into account	%
Margin improvement, CCC	Percentage change of margin by comparing new case to base case, considering carbon capture cost (CCC)	%

TABLE 2. SIMULATION KPI RESULTS (CHANGING S/C AND COT SCENARIOS)

Steam cracker KPIs	Base case	(A) Changing steam to hydrocarbon ratio (S/C)		(B) Changing coil outlet temperature (COT)	
Adjusted variable		0.3	0.5	825°C	855°C
Firebox efficiency, %	36.4	36.7	36.1	37.9	35.1
Bridge wall temperature,°C	1,129	1,224	1,235	1,206	1,250
Ethylene yield, wt %	38.7	39	38	33	43
Severity, P/E	0.254	0.241	0.264	0.254	0.187
Fuelgas consumption	5.3, 789	5.1, 761	5.5, 816	4.8, 715	5.7, 859
Energy intensity	19.30	19.39	20.52	21.63	20.12
Emissions efficiency KPIs					
Fluegas rate	128, 152	123, 151	132, 157	116, 138	139, 165
Fluegas composition (CO_2, 0_2)	5.4, 1.6	5.4, 1.6	5.4, 1.6	5.4, 1.6	5.4, 1.6
Carbon intensity	0.77	0.73	0.80	0.77	0.78
Energy savings %		–3.42	2.12	7.19	0.15
Emission reduction %		–3.5	3.4	–9.3	8.86
Margin improvement, CT		0.43	–0.56	–9.2	4
Carbon-capture (CC) KPIs					
CC efficiency (emission reduction)	85	87	83	91	79
CC energy intensity	5.34	5.40	5.35	5.10	5.30
Margin improvement, CCC	2.8	4.2	3.15	–5.8	11.3

Base case: S/C = 0.4 wt./wt., COT= 840°C, Excess air = 10%, CH_4/H_2 = 4 wt./wt., Air temperature = 60°C

gen and oxygen, while SMR produces hydrogen from natural gas with carbon capture or electrified SMR with no emission. All methods offer opportunities to incorporate clean hydrogen into the furnace operation. These upgrades not only lower energy consumption but also set new benchmarks for decreasing emissions [*12–15*].

Oxy-fuel combustion is an innovative approach that uses pure oxygen instead of regular air for combustion. This approach eliminates nitrogen from the combustion process. Oxygen is separated from the air separation unit (ASU). The oxygen is mixed with recycled fluegas to lower the flame temperature. The fluegas is a mixture of steam and concentrated CO_2, where the steam is easily separated through condensation and the remainder is pure CO_2. Additionally, oxy-fuel combustion reduces the volume of fluegas that may require carbon capture [*12–15*].

Post-combustion strategies. Improving combustion processes and employing advanced emission-control technologies assist in emissions reduction, but further emission reduction and elimination may be needed to meet certain regulations.

After minimizing emissions through the optimization of the steam-cracking process and combustion, the next step involves removing any remaining CO_2 emissions from the exhaust fluegas. The objective is to capture and remove fluegas emissions to mitigate environmental impact, which is called post-combustion capture. As part of post-combustion capture, heat recovery from furnace fluegas can be utilized to preheat combustion air, thereby improving energy efficiency and reducing CO_2 emissions. In the case of conventional steam crackers, post-combustion technologies can be implemented independently without the need for pre-combustion processes or optimization of the furnace and combustion section [*12–15*].

In post-combustion processes, CO_2 is separated and captured from conventional fluegas using various methods, including cryogenic distillation, membranes and physical and chemical absorption, with the latter being the most widely used. The adsorption efficiency varies from 80 to 95%, with the regenerator energy costs ranging from 3 to 5 GJ/m.t.$_{CO2}$ [*12*].

For most conventional plants, decarbonizing steam crackers by post-combustion technologies would be a feasible solution because few changes are needed for the current plant if the required energy for regenerator and compressor is available. For these units, the energy source could be low-pressure steam from the steam system or from process electrification [*8*].

The captured and compressed liquified CO_2 can be sent to storage or to a utilization process. At this point, CO_2 can be converted into methanol through hydrogenation, followed by methanol-to-olefin conversion. Conversely, CO_2 can be converted into ethanol and then into "green" ethylene and polyethylene. Additionally, CO_2 can be fed to dehydrogenation and methanation processes to obtain methane. Another potential CO_2 utilization method could be the production of sustainable aviation fuel (SAF) through the Fischer-Tropsch process [*15*].

Simulation and optimization

Process simulation software provides a versatile and accurate platform for techno-economic assessment of decarbonization strategies. Process simulation software can be used to perform unit monitoring, optimize processes and create a digital twin of the steam cracker. This approach enables engineers and technologists to study the effects of many factors, such as hydrocarbon feed, steam properties, coking inhibitors, fuel flowrates, operating conditions, coil configuration and type, coil metallurgy, wall coatings and emissivity, on energy efficiency and overall performance. Consequently, strategies for reducing coke and carbon emissions can be studied to make informed decisions before implementing changes in the plant.

For the study in this article, a process simulation software including an integrated steam-cracker-furnace

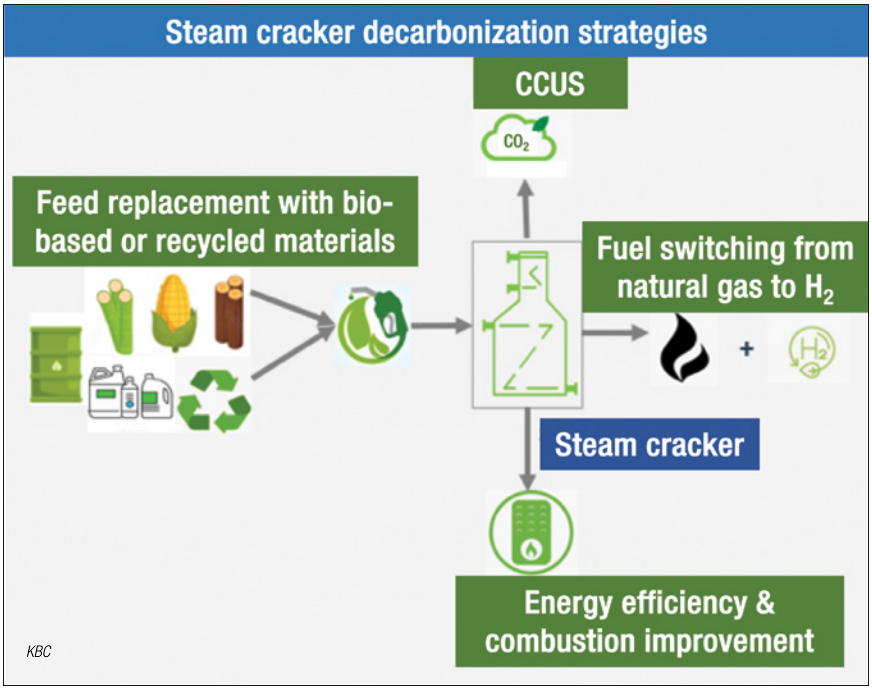

FIGURE 2. Several decarbonization strategies related to steam crackers have been identified as promising paths toward net-zero emissions

model was applied to examine various decarbonization strategies and evaluate energy efficiency and CO_2 capture from fluegas.

The model contains numerous parameters, including feedstock composition, operating conditions, equipment configuration and heat-transfer mechanisms. By simulating the real-world furnace behavior and characteristics, the software provides a virtual environment to experiment with different scenarios for decarbonization.

The study explored the impact of various parameters on the performance of the cracker, focusing on energy efficiency and emissions intensity. The primary objective was to minimize emissions and associated costs, while maximizing energy efficiency, product yields and resulting profit. The profit is determined by the difference between revenue and costs, where revenue is derived from products sales and costs encompass expenses such as feedstock and utilities. By optimizing these parameters, this investigation provides the means to select the most effective decarbonization strategies.

Results and discussion

Process simulator software was used to investigate and analyze the effect of different scenarios related to the energy efficiency and CO_2-emissions reduction of the steam cracker, as follows:

(**A**) Altering the hydrocarbon feed ratio (S/C)
(**B**) Altering the coil outlet temperature (COT)
(**C**) Adjusting excess air
(**D**) Adjusting fuel composition (fuel switching)
(**E**) Multi-objective optimization

This study examined these scenarios because they require relatively minor physical modifications and can be readily implemented into existing plants. To perform this analysis, several key performance indictors (KPIs) were considered, whose definitions are provided in Table 1. In Table 1, the margin is defined as: *margin* = *revenue* – *cost*, where revenue is related to product yield and price, and product yield is a function of S/C and COT.

Cost is calculated as *cost* = *feed cost* + *energy cost* + *emissions cost*, where energy cost is a function of energy type, rate and price, and emissions cost is a function of emissions rate and emissions cost index.

For the study's base case and (A)–(E) scenarios, two types of margin calculation are considered: one incorporating a carbon tax (CT) index of $0.05/kg$_{C2,C3}$ and the other con-

TABLE 3. SIMULATION KPI RESULTS (CHANGING EXCESS AIR AND FUEL COMPOSITION SCENARIOS)					
Steam Cracker KPI	**Base case**	**(C) Excess air, wt %**		**(D) Fuel composition (CH_4, H_2)**	
Adjusted variable		5	15	(CH_4 = 0.4 wt %, H_2 = 0.6 wt %)	(CH_4 = 0.6 wt %, H_2 = 0.4 wt %)
Firebox efficiency, %	36.4	38.4	34.4	39.1	38
Bridge wall temperature, °C	1,129	1,233	1,227	1,229	1232
Ethylene yield, wt%	38.7	38.6	39.0	38.6	38.6
Severity, P/E	0.254	0.255	0.251	0.256	0.255
Fuelgas consumption	5.3, 789	5.1, 757	5.5, 822	3.5, 1,125	4.2, 990
Energy intensity	19.31	19.13	19.51	19.06	19.16
Emissions efficiency KPIs					
Fluegas rate	128, 152	117, 140	139, 165	110, 130	117, 139
Fluegas composition (CO_2, O_2)	5.4, 1.6	5.66, 0.9	5.23, 2.30	1.98, 1.57	3.44, 1.6
Carbon intensity	0.77	0.74	0.80	0.25	0.46
Energy savings		0.93	1.035	–1.29	–0.77
Emission reduction		–3.9	4.2	–67.3	–40.5
Margin improvement, CT		0.43	–0.35	–10.9	–6.1
Carbon-capture (CC) KPIs					
CC efficiency (emissions reduction)	85	88	82	96	97
CC energy intensity	5.34	5.42	5.30	5.43	6.10
Margin improvement, CCC	2.8	3.3	3.15	–8.2	–3.9
Base Case: S/C = 0.4 wt./wt., COT= 840°C, Excess air = 10%, CH_4/H_2 = 4 wt./wt., Air temperature = 60°C					

sidering CCUS cost ranging from \$15–25/m.t. CO_2.

Scenarios (A) and (B). In Table 2, the results from the base case simulation are compared with the process variations resulting from scenarios (A) and (B). The implementation of the carbon capture technology for this cracker scenario results in 85% reduction in emissions as a result of carbon-capture efficiency, coupled with a 2.8% improvement in margin attributed to the lower cost of carbon capture in comparison to expenses associated with carbon emission taxes.

The second and third column present the effect of altering the hydrocarbon feed ratio and coil outlet temperature, respectively, on the furnace performance. The findings demonstrate that augmenting the S/C ratio from 0.3 to 0.5 wt./wt. results in a 7.8% rise in energy consumption, along with an approximately 5.8% increase in energy intensity (GJ/m.t.$_{C2,\ C3}$), a 7.2% elevation in carbon emissions and a 9.5% uptick in carbon intensity (CO_2 kg/kg$_{C2,\ C3}$). Raising the COT from 825 to 855°C results in an 6.9% increase in fuel consumption and a 1.2% rise in CO_2 emissions. Nevertheless, the energy intensity and emissions intensity remain nearly constant, as the 10% enhancement in ethylene yield compensates for the increase in energy consumption and emissions.

Scenario (C). In Table 3, the first column corresponds to the base-case simulation results, while the second and third columns denote the impact of adjusting excess air (C) and fuelgas composition (D), respectively, on the furnace performance.

Excess air plays a pivotal role in fuelgas combustion within the burner, which is controlled by the CO composition at the bridgewall or fluegas exhaust. The presence of CO in fluegas indicates poor combustion and fuel loss, necessitating targeted emissions control and prevention, due to health and safety hazards and environmental impacts. Elevating excess air from 5 to 15 wt. % for achieving complete combustion leads to an 8.5% increase in fuel gas consumption. This elevation results in a 1.98% increase in energy intensity and an 8.1 % increase in carbon intensity.

Excess air beyond the necessary quantity for complete combustion needs to be regulated, as an increase in excess air raises both energy intensity and carbon intensity, thereby lowering furnace thermal efficiency. Therefore, an optimal amount of excess air of around 5 to 10% is recommended.

The required heat source for thermal cracking reaction is radiation, which is provided through combustion of hydrocarbon fuelgas, mainly methane, in the burner. Hydrogen integration involves substituting hydrogen for a portion of the hydrocarbon fuel, reducing or eliminating CO_2 emissions. Furthermore, due to the heating value of hydrogen, increasing hydrogen percentage of fuel reduces fuel consumption, which improves energy efficiency. In cases where blue hydrogen is employed, pre-combustion technology is utilized. This involves the production of hydrogen through either autothermal reforming or steam reforming, accompanied by a carbon capture unit to mitigate emissions. Conversely, when green hydrogen is utilized, hydrogen is produced from electrified reformer furnaces or electrolyzers.

Scenario (D). Table 3 also illustrates the impact of hydrogen fuel switching within two scenarios, where the hydrogen content of fuel is increased beyond the base case (where H_2 = 10 wt. %). In the first scenario, CH_4/H_2 = 1.5 and H_2 is increased to 40 wt. %, and in the second scenario, CH_4/H_2 = 0.66 and H_2 is increased to 60 wt. %. In these scenarios, there is a significant reduction in both CO_2 emissions and carbon intensity (about 70%), accompanied by a decrease in both energy consumption and energy intensity by approximately 1%.

The economic and environmental feasibility of utilizing hydrogen as a fuel for carbon reduction hinges on several factors, such as carbon tax considerations and the prices of hydrogen and for CCUS. Two cases

are studied: one with carbon tax included and the other with CCUS.

The comparison margin of both cases with the base case are presented in Table 3. In the first case, where a carbon tax index of 0.05 $/kg$_{C2,\ C3}$ and a hydrogen price of $2/kg$_{H2}$ were considered, decreasing the CH_4/H_2 ratio leads to a marginal loss of about 5.4%. In the second case, considering CCUS cost of 15–25/m.t. CO_2 and a hydrogen price of $2/kg$_{H2}$, changing the CH_4/H_2 ratio reduces the margin by 4.6%.

The results of the various investigated scenarios in this study show that hydrogen integration with combustion fuel has the highest impact on emission and energy intensity reduction. However, components like carbon tax index, CCUS cost and the price of hydrogen determine if this method is economically viable and sustainable.

TABLE 4. SIMULATION KPI RESULTS (MULTI-OBJECTIVE OPTIMIZATION CASE)

Steam Cracker KPI	Base	(E) Optimized case
Adjusted variable		
Firebox efficiency, %	36.40	39.54
Bridge wall Temp, °C	1,129	1,230.9
Ethylene yield, wt %	38.70	39.1
Severity, P/E	0.254	0.247
Fuelgas consumption	5,295, 789	4,006, 944
Energy intensity	0.35	18.42
Emissions efficiency KPIs		
Fluegas rate	128/152	109.9, 129
Fluegas composition (CO_2, O_2)	5.44, 1.6	3.5, 1.12
Carbon intensity	0.77	0.43
Energy savings		–4.6
Emissions reduction		–44.2
Margin improvement, CT		0.63
Carbon-capture (CC) KPIs		
CC efficiency	85	98
CC energy intensity	5.34	5.50
Margin improvement, CCC	2.80	3.72

Base Case: S/C = 0.4 wt./wt., COT= 840°C, Excess air = 10%, CH_4/H_2 = 4 wt./wt., Air temperature = 60°C

Scenario (E). In the final study, outlined in Table 4, a combination of investigated scenarios is examined (E). In this scenario, a multi-objective optimization scheme is employed by defining object functions aimed at maximizing margin and reducing energy consumption and emissions. The defined objective functions prioritize maximizing yield while minimizing emissions rates and energy consumption by adjusting independent variables (such as S/C, COT, excess air and CH_4/H_2 ratio). The optimal operating conditions derived from this analysis are as follows: S/C= 0.33 wt./wt., COT = 844°C, excess air = 7%, hydrogen-rich fuel composition of CH_4/H_2 = 1.5 wt./wt. Table 4 presents the KPIs under these optimum conditions for steam cracker decarbonization. Notably, this approach results in an energy saving of about 4.6% and emission reduction by 44%, while achieving a marginal gain of about 3.7%. The subtle increase in margin is attributed to reductions in energy cost via reduced fuel consumption, decreased cost associated with carbon capturing due to CO_2 emission reduction and improvements in ethylene yield and radiation efficiency.

The integration of a gas turbine (GT) with a steam cracker is another applied method to realize energy savings in olefin plants. This technology facilitates energy savings through the dual mechanisms of electricity generation and reduction of energy consumption in the convection section of the furnace. The improved energy efficiency attained via GT implementation is realized by utilizing the hot fluegas generated in the GT to provide oxygen-rich, preheated air. This air is then mixed with fresh air, serving as combustion air for the burner heater. This process leads to significant energy savings by effectively reducing energy intensity [*19*].

GT implementation may not be feasible for every existing steam cracker due to certain limitations. Specifically, the increased rate of hot fluegas necessitates a larger

convection section, which may not be feasible for all facilities. However, this technology can still be applied to current steam crackers by selecting the appropriate integration concept. It is important to note that integrating a GT may also require a larger convection section for the steam-generation bank.

Conventional GT-equipped furnaces do not inherently contribute to emissions reduction due to the utilization of hydrocarbon fuelgas for GT combustion. To fully leverage the energy-efficiency benefits of GT technology while addressing emissions concerns, the same strategy as for emissions reduction in radiation-box combustion is proposed. This approach involves integrating hydrogen into both GT fuel and burner fuel, alongside the option carbon capture for the emitted CO_2.

Beyond the scope of this study

Note that this study does not consider all possible variations that can impact process carbon intensity and energy efficiency. Some of the considerations that were outside the scope of this study are discussed below.

Emissivity. Emissivity analysis on emissions reduction is excluded from this study, since increasing emissivity requires changing the refractory coating, and this study only investigated methodologies that require minimal changes to the existing plant. However, it has been reported that using a high-emissivity coating for the refractory wall improves radiation heat transfer and consequently increases the furnace's thermal efficiency by 1.9% and decreases CO_2 emission by 4% while reducing emissions [*19*, *20*].

Unconventional feedstocks. Applying CCUS, CO_2 emissions emitted from the steam cracker are captured and converted into valuable products. Captured CO_2 can be used as a feedstock for rWGS and Fischer Tropsch, methanol-to-olefin conversions and methanation. These technologies transform CO_2 emissions into synthetic feed for refinery and petrochemical operations while reducing greenhouse gas emissions. Further studies will analyze the lifecycle of decarbonization using unconventional feedstocks with bio-feed and plastic recycling and CCUS.

Final thoughts

A combination of factors must be considered when determining the most efficient and economically feasible methods for decarbonizing steam crackers. These factors include technological innovation, technical feasibility, economic viability, scalability and environmental impacts.

Economic feasibility is crucial for the successful adoption of decarbonization strategies. The cost of carbon capture and utilization processes and the cost of hydrogen for fuel switching must be competitive with conventional methods. Invest-

ments in research and development are also crucial to drive down costs and improve the economic viability of these approaches. Depending on the target of the olefin plant, increasing olefin yield, severity and, consequently, margin or emissions and energy reduction, different strategies could be taken. In addition, considering carbon taxes or carbon capture cost can further influence the margin.

The study outlined here shows that hydrogen integration (partial or complete) is the most efficient way to decarbonize steam crackers, while resulting in energy savings by lowering fuel consumption rate. However, switching to a rich hydrogen feedstock may require a revamp of the unit due to operational and design constraints that must be addressed. In the next few years, by lowering the cost of blue or green hydrogen, fuel switching to hydrogen will become even more economical. ■

Edited by Mary Page Bailey

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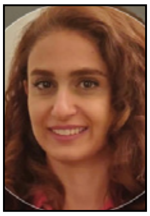

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AI-Powered Search Improves Knowledge Transfer at Agricultural Chemicals Site

An artificial intelligence (AI)-based search tool allowed workers to quickly mine historical data to improve operations and respond to emerging problems

Andreas Eschbach
eschbach GmbH

At the Bayer Crop Science facility in Muttenz, Switzerland, managers and workers wanted to improve communication during shift handovers and enable more efficient knowledge transfer. The site had already digitized its shift handover notes, giving personnel a vast repository of historical data, but its next challenge was how to locate relevant information quickly on the shop floor. A smart search system powered by artificial intelligence (AI) has helped them mine these data to drive operational improvements and respond quickly to emerging issues.

FIGURE 1. Natural language processing (NLP) allows employees to use plain language, rather than keywords, to query the data contained in the shift handover system

Inefficient knowledge transfer

"Knowledge transfer is a big issue in shift operations," says Matthias Hesskamp, head of site operations and excellence at Bayer Muttenz. "Shifts are producing and generating data 24/7, but the Day Operations staff, who are responsible for problem solving, are only onsite working 40 hours per week," he explains. "That team faces the challenge of processing data that are generated constantly every day."

To enable better communication across shifts and teams, Bayer Muttenz implemented a digital shift handover system, known as Shiftconnector by eschbach GmbH (Bad Säckingen, Germany; www.eschbach.com), about ten years ago. The software now acts as a centralized database and communication platform, capturing shift notes and other critical plant data in one location (Figure 1). This improves information flow and transparency, since employees know where to find updated information from recent shifts that they need to do their jobs. Over time, Shiftconnector has become a valuable repository of historical knowledge.

Bayer Crop Science process specialist Sven Kränkel explains, "Shiftconnector is mostly kept up to date by the shift teams working on site. They enter data on how the plant is operated, any disruptions or incidents, what ran well, and what optimizations were implemented. The Day Operations team needs exactly these pieces of information to assess whether the production went to plan. Did we have any disruptions? Were they recurring ones? This allows us to evaluate the production process and plan ahead for the coming days, weeks and months."

However, finding the information at the time it was needed proved to be a challenge — especially if entries were incomplete or searchers did not know the exact correct search term needed to uncover the information. Using standard keyword-based search tools was inefficient and did not always return the most relevant results.

Shift collaboration system

Eschbach worked with Bayer Crop Science in Muttenz to develop a customized Smart Search tool with AI that could be used inside Shiftconnector. Natural language processing (NLP) allows employees to query the system in plain language, without worrying about exact keywords. An example query could be, "has this product output ever turned brown before?". NLP allows the system to analyze unstructured data like manual shift notes to understand their contents and find relevant results, while machine learning (ML) enables it to look for patterns in vast amounts of data.

To make the system usable, the AI had to be trained on domain- and site-specific language, including technical terms and abbreviations. Eschbach worked with Bayer Crop Science and leading AI researchers at the University of Göttingen to adapt an off-the-shelf AI search tool for their needs. It took two years of development, prototyping and beta testing, which included user groups, workshops and onsite investigations to gather insights into users'

workflows and requirements as well as domain- and company-specific language. The result was a customized AI Smart Search solution that understands their language, workflows and user needs.

Results: impact on plant

AI-driven Smart Search has significantly reduced the amount of time that it takes workers to find relevant entries in their shift handover software. For example, if a problem develops (such as a blocked pipe), AI search allows them to quickly find all the previous times similar issues have arisen, look for patterns that might suggest a cause, and discover what remedies have been effective in the past. It is also faster and easier to find data requested during audits and locate information for operational decision making. Boyjan Guetlin, who works in operational excellence at Bayer Muttenz, says, "Our shift workers did not take long to realize the benefits of Smart Search. Search times were reduced, and information is available for longer. This saves resources and leads to much positive feedback from the shifts."

Bayer Crop Science shift supervisor Martin Aregger especially appreciates the time saved during troubleshooting. He says, "Smart Search saves us a lot of time, often several hours. Before, I had to research myself how the problem was dealt with in the past. Now, it takes me only a few minutes to gather all the facts before I can tackle the problem and resolve it relatively quickly. Before, it took me hours just to work out an initial approach."

Providing faster, easier access to historical data allows workers at all levels to do their jobs better and more efficiently. A centralized knowledge management system with Smart Search also preserves valuable information and knowledge for the future.

Process manufacturers are facing a knowledge exodus as experienced workers retire. At the same time, a shortage of skilled workers makes recruiting and retaining workers, and getting them up to speed quickly, essential. Aregger notes, "In principle, you can also store everything in the tool that is necessary for a good introduction. And they can call up the information themselves by entering search terms. This will give them a chance to make an active contribution and to quickly integrate with our company and feel at home here."

The new tool has been well accepted by employees at all levels in the company. Smart Search is helping Bayer to streamline operations, improve efficiency and reduce the time it takes to identify, troubleshoot and respond to problems. Hesskamp says, "AI will lead to substantial gains in efficiency. As a supporting tool for our employees, it will help them to find data, generate knowledge and solve problems." ■

Edited by Scott Jenkins

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Coriolis Flowmeters: Insights for Selection and Upgrade

Coriolis mass flowmeters are available with a range of body styles and transmitters, enabling significant functionality improvements without sensor replacement

Brett Sibel
Emerson

Coriolis meters have long been a mainstay in the chemical process industries (CPI), providing highly accurate mass-flow measurements for raw-material charges, combustion control feeds and countless other process flows. These meters also measure both density and temperature, allowing them to be used for reactor split detection, and to measure inferred variables, such as acid or base concentration, oil-water ratios and many others.

New designs extend the capability of these types of meters significantly by enabling the upgrade of existing Coriolis transmitters to take advantage of new hardware, software and diagnostic features — without the need to replace legacy Coriolis sensors.

Most flowmeters cannot measure mass directly, but instead measure fluid velocity and use the pipe diameter to calculate volumetric flow. They then use assumed constants to convert that volumetric flow to a mass-flow equivalent. This provides an acceptable level of accuracy in some applications, provided that fluid density and temperature remain constant and match the values used in the calculation. Unfortunately, process conditions in many CPI applications tend to vary considerably, creating errors. However, Coriolis meters provide a solution to these and other flow measurement issues.

Coriolis meter advantages

Coriolis meters are one of the few flowmeter types that can directly measure the mass flow of either gases, liquids or slurries. They also simultaneously directly measure density and temperature, providing three vitally important measurements within a single meter. Most importantly, the mass-flow measurement remains accurate despite process variation, allowing production units to consistently close the loop on process mass balances and optimize production. Coriolis is also generally the technology of choice for raw-material charges and final-product flow measurement.

Highly accurate flow, density and temperature readings also allow Coriolis meters to make inference measurements — such as combustion-fuel quality, concentrations of acids and caustics and final-product quality or mixture ratios. These very robust measurements can be used as control points to replace expensive analyzer-based measurement units, which often require frequent maintenance.

But like every instrument, Coriolis meters do have their limitations. Historically, the sensors have tended to be large and expensive. The transmitter offerings were generally limited and rather costly as well, often offering area classifications and a multitude of inputs and outputs (I/Os) that are not necessary for many applications. Fortunately, these issues are being addressed with a host of revised sensor and transmitter designs.

Coriolis sensor options

There are now a range of Coriolis sensors designed to work well

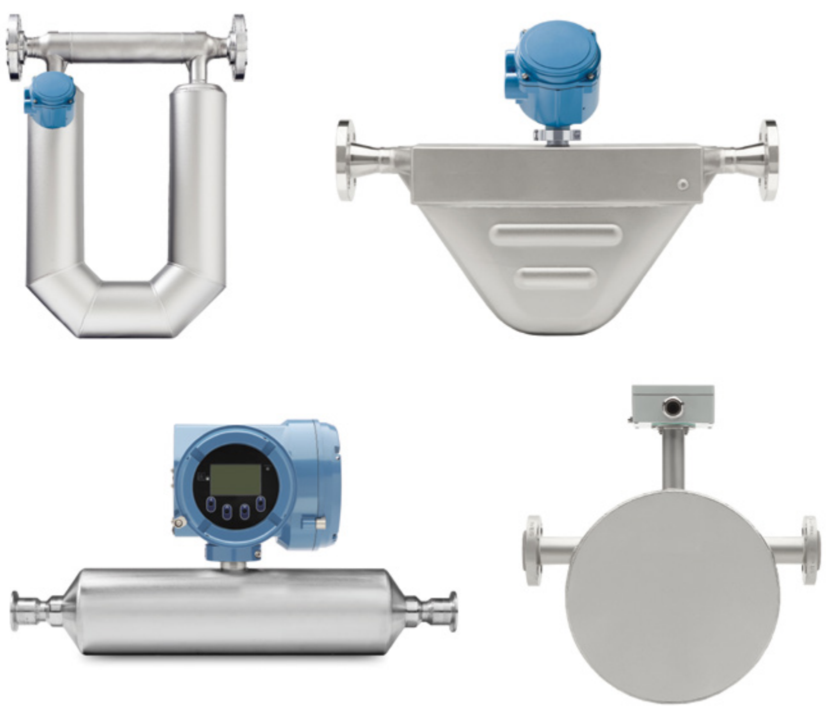

FIGURE 1. Advances in instrument design are enabling new applications for Coriolis meters

in a variety of processes (Figure 1). Typical applications use the basic U-tube type design (upper left image in Figure 1), with various form factors. Very high accuracy requirements necessitate the use of a larger U-tube to maximize signal-to-noise ratio, however, more compact designs are now available. These designs remain accurate, but have a smaller piping take-out and much reduced body size, made possible in part by a V-shaped tube. Beyond those sensors, there are many other options, including: straight-through, single-tube sensors that reduce plugging and can be pigged; all-tantalum body designs for corrosive liquids; and specialty meters designed for compressed or liquefied natural gas (CNG and LNG), hygienic applications; and designs for very high pressures up to 15,000 psi.

Sensor cost will vary considerably depending upon the body type, but the broad range of available options allows a user to find a suitable sensor to meet their specific application requirements and budget.

Transmitter improvements

There have also been significant technological advances in Coriolis transmitters, including new hardware capabilities and software enhancements. Historically, Coriolis transmitters had somewhat limited options, with only full-featured and expensive models available. To address varying needs, a range of Coriolis transmitters are now offered that include different electric classifications and I/O offerings, with enhancements that can be added as needed. This scalability of features allows users to choose a transmitter that meets their requirements without paying for unneeded or redundant features.

For instance, a typical high-tier Coriolis transmitter might carry Class 1, Div. 1 electrical classifications and have a large number of fixed I/O channels. Less expensive transmitters are now available for Class 1, Div. 2 or unrated electrical areas, and the I/O offerings have a smaller number of configurable channels to suit specific needs. There are also different housings available — such as standard painted aluminum or 316 stainless steel — to handle various process environments, and most of the transmitters can either be integral to the sensor or remote-mounted (Figure 2).

New transmitters offer expanded hardware features that vary by model, but typically include options to energize the unit with a.c., d.c., two-wire power, or Power over Ethernet. Bluetooth access is another valuable feature offered with some models, as well as other connectivity options, including Modbus RTU, Modbus TCP, HART RS-485 or EtherNet/IP. Some units now offer configurable I/O, which allow specific channels to be set up for HART analog, frequency, digital inputs, digital outputs or various other digital communication options.

FIGURE 2. Coriolis transmitters are now offered with a wide range of housings, classifications and hardware offerings

Many of the latest Coriolis transmitters can be configured without opening the cover using WirelessHART, secure Bluetooth connectivity or capacitance touch sensors on the graphical display. Most models also offer a USB port for fast configuration download or backup, and several Coriolis transmitters on the mar-

FIGURE 3. Some Coriolis transmitters have been specifically designed to interface with a wide variety of legacy Coriolis sensors, allowing existing sensors to take full advantage of enhanced connectivity and software capabilities

ket are certified for use in areas rated with a safety integrity level (SIL) 2/3.

Coriolis software enhancements

Transformational advancements have been introduced in the software that operates within the Coriolis transmitter. There are now a broad range of enhanced capabilities offered as individually licensable options. Some of the new features include:

- Smart meter verification that can continuously monitor key performance indicators, like tube stiffness in Coriolis meters, to maintain measurement accuracy and meter integrity, thus driving cost reduction through early detection of issues
- Advanced phase measurement, which can detect and measure liquid and gas flow in multiphase applications, such as wellhead or oil-separator applications
- Petroleum measurement and American Petroleum Institute (API) correction software for API gravity and reference temperature and pressure compensation
- Net-oil computer calculations
- Concentration measurement software to calculate various measurements of dissolved solids, as well as specific gravity and other concentration measurements
- Piecewise linearization for enhanced gas applications
- Data historian with a real-time embedded clock
- Time-stamped digital audit trails and reports for agency compliance

Most of these software features are available as options that are specified when the transmitter is purchased. If a particular software feature is required after installation, it can be purchased and added later.

Legacy upgrades

One significant advancement is the introduction of new Coriolis transmitters that have been specifically designed for retrofit onto legacy sensors (Figure 3). These units allow the user to keep their installed sensor in place, and simply replace the transmitter to take full advantage of new hardware and software enhancements. Transmitter replacement involves only a few simple steps and can be completed without breaking process lines or making any pipe modifications. Once replaced, the new transmitter provides access to the advanced diagnostics, broad connectivity options and process calculations currently available in the latest Coriolis meters.

For users with existing Coriolis meters, there are now transmitter upgrade options that allow the facility to take advantage of the latest diagnostics and advanced calculations, without incurring the downtime and expense of sensor replacement.

If faced with the need to specify a new Coriolis flowmeter or upgrade an existing sensor, users should fully understand the assortment of sensor and transmitter options that have recently become available. Coriolis meters have always been a premier flow-measurement device, but the latest technological advances make these meters even more capable and affordable. ■

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All figures courtesy of Emerson

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VALVE WORLD EXPO DÜSSELDORF

The Valve World Conference & Expo (www.valveworld-expo.com) is being held December 3–5 in Düsseldorf, Germany. One of the world's largest events for industrial valve technologies, this year's Valve World boasts nearly 400 exhibitors covering the full spectrum of the industry. In addition to the exhibition hall and a robust technical conference program, the event is also hosting the ecoMetals initiative, which will highlight sustainable developments from the valve industry, including new technologies for producing "green" steel and other metals. The following is a small selection of the equipment and technologies that will be showcased at Valve World's exhibition hall.

Modularity eases installation and design of valve systems

In the MODU ONE modular valve system (photo), different types of valves share the same dimensions and connections and spare parts have multiple functions, forming a modular approach that aims to ease installation, maintenance and the creation of 3D-drawings. Furthermore, the system is backward-compatible with existing products and spare parts (such as seat rings and gaskets). Additionally, MODU Safe Mounting (MSM) functionality focuses on error-free installation and robust process-safety management. Hall 1, Stand E59 — *MODU Valves A/S, Vejle, Denmark*
www.moduvalves.com

This flexible mounting kit improves actuator flexibility

The new LinKit-Maxx mounting kit (photo) enables users to utilize both sides of a linear actuator for component mounting. It provides the opportunity to combine positioners with limit-switch boxes and solenoid valves, or mount two limit switch boxes for redundant feedback to enhance the safety integrity level (SIL). The modular design of LinKit-Maxx facilitates the mounting of various components, such as limit-switch boxes, dual sensors and positioners, as well as inline solenoid valves. The LinKit can be used for cast-iron yokes and rod-type yokes. The manufacturer provides different lever lengths for various strokes, and thanks to the modular design, users can easily select and order the necessary mounting accessories. All parts are made of high-quality AISI304 stainless steel with thickness deliberately chosen for robust construction, making the LinKit very durable and corrosion resistant. Hall 1, Stand B32 — *Eurotec Antriebszubehör GmbH, Langenargen, Germany*
www.eurotec.global

Smart actuators designed for harsh process environments

Tigron actuators (photo) are specifically designed to meet the demanding requirements of oil and gas applications, from production, storage and transport to downstream processing. Tigron actuators are ATEX- and IECEx-certified for the highest gas group IIC T4, which includes hydrogen. A wide temperature range of –65 to 75°C, IP68 protection and an extremely resistant powder coating ensure that Tigron devices operate safely and reliably in harsh environments. The smart actuators are available in different sizes and combinations to suit all valve automation tasks in the medium to high torque and thrust ranges. Hall 3, Stand E74 — *AUMA Riester GmbH & Co. KG, Müllheim, Germany*
www.auma.com

Improve safety and efficiency with these sampling systems

This company's lined reactor sampling systems (photo) offers efficient sampling without interrupting the ongoing process. These systems enable the closed and representative sampling of substances from reactors and vessels by using either vacuum or positive pressure. Lining the fittings with PTFE or PFA protects the system and the environment from corrosive chemicals and aggressive process media. This extends the service life of the system and minimizes maintenance costs. Sampling takes place without dead space, which re-

Eurotec Antriebszubehör

MODU Valves

AUMA Riester

Swissfluid

duces the risk of contamination and maintains the quality of the samples taken. As there are no reactions with the system's environment, the reproducibility and accuracy of the samples, which are crucial for process monitoring and quality control, are guaranteed. Manual and automated systems meet the highest occupational safety standards. The modular design allows the integration of additional fittings. Hall 1, Stand E57 — *Swissfluid AG, Lenzburg, Switzerland*
www.swissfluid.ch


ABB Instrumentation

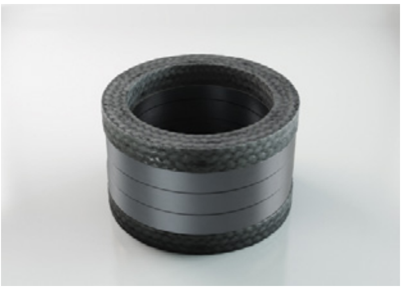
Digital positioners offer automation versatility

This company's digital positioners (photo) are compatible with all types of valves and offer several key differentiators, including low steady-state compressed-air consumption that saves money and reduces the carbon footprint. They can be set up with a single key function, which saves time in commission and startup. Other features include advanced auto-adjust functionality, which eliminates setup errors, and adaptive control functionality for real-time optimization that ensures high position accuracy. The product offering of positioners includes the EDP and TZIDC brands. TZIDC positioners are newly equipped with contactless position sensing. Hall 1, Stand A13 — *ABB Instrumentation AG, Minden, Germany*
www.abb.com


Rotork

This ethernet-enabled actuator accelerates data analysis

This company is introducing an integrated ethernet actuator (photo), which is compatible with ethernet/IP Modbus TCP and Profinet protocols. With the introduction of this integrated Ethernet solution, a data gateway is no longer required, enabling a direct, streamlined connection to the company's intelligent IQ3 Pro actuator. This reduces complexity and increases the volume and speed of data extraction, with transfer rates up to 100 Mbps. The solution is also housed within a robust weatherproof or explosion-proof enclosure and supports RJ45 and M12 connection standards. This Ethernet solution accelerates data transfer and enhances the capability for in-depth data analysis. By leveraging the Intelligent Asset Management (iAM) cloud-based system, operators can unlock powerful insights from their operational data. This enables predictive maintenance, optimized performance and informed decision-making, driving productivity and reducing downtime. Hall 1, Stand C33 — *Rotork PLC, Bath, U.K.*
www.rotork.com


James Walker

New packing product provides robust sealing compliance

The Supagraf 100FXI CS packing combination set (photo) has been developed specifically to exceed the requirements of all current fugitive-emissions standards. Qualified for the requirements of the API 622, 3^{rd} ed. standard, including Annex-C (HT) 2022, through testing carried out by Yarmouth Research and Technology in the U.S., Supagraf 100FXI CS achieved maximum fugitive emissions levels of 10–12 ppm over 1,510 cycles with no loss of torque and no adjustment required at any point in the test. The packing set is also certified Fire Safe to the standards set forth in API 607, 8^{th} ed., with zero leakage during and after fire, and has been qualified to meet API 624, 2^{nd} ed. standards, including Annex D (HT), API 641, 2^{nd} ed., including Annex C (HT), and the ISO 15848 standard up to 400°C. The new product joins the Supagraf product range, which is designed for valve-stem sealing and emissions reduction when handling oxygen, hydrogen, molten salt and hydrocarbon media. Hall 1, Stand D17 — *James Walker Ltd., Surrey, U.K.*
www.jameswalker.biz


Conflow

Smart positioners with automated diagnostics and calibrations

Along with partner Power-Genex Ltd. in South Korea, this company is launching new ranges of intelligent positioners for linear and rotary valves, Series ASD5000 and 7000 (photo). The new products include many advanced features, such as enhanced auto-diagnostics with HART protocol, auto-calibration, non-contact position sensors and a large multilingual display with real-time information and graphs of control variables. Hall 1, Stand E78 — *Conflow S.p.A., Agrate Brianza, Italy*
www.conflow.it ■

Mary Page Bailey

Europe

special advertising section

Inside

Heat pumps powering sustainable industrial heating solutions

MAN Energy Solutions' high-efficiency heat pumps transform industrial heating applications with scalable and sustainable solutions.

As industries worldwide seek to reduce their carbon footprints, MAN Energy Solutions provides state-of-the-art heat pumps that plays a crucial role in decarbonizing industrial processes. With many years of experience in providing expertise to industrial customers, the company leverages its deep knowledge of industrial processes to offer new heat pump solutions. This innovative technology not only reduces emissions but also optimizes energy use across diverse sectors.

Meeting market demand for decarbonization with heat pumps

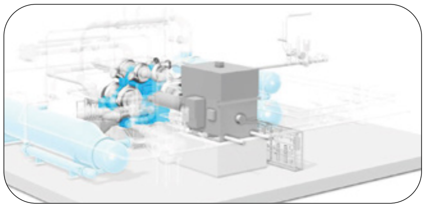
With global energy demands rising, industries are under increasing pressure to transition to low-emission technologies. MAN Energy Solutions' vapor compression cycle (VCC) heat pumps address this challenge by providing reliable, energy-efficient heating solutions tailored to industrial needs. By tapping into renewable energy sources and waste heat recovery, these heat pumps significantly reduce fossil fuel dependence while offering impressive efficiency gains.

Technological advantages

The core of MAN Energy Solutions' solution is its VCC heat pump technology, designed to deliver maximum output with minimal energy consumption. Operating at temperatures up to 140 °C for hot water and up to 300 °C for steam supply, these heat pumps can cover a wide range of industrial applications. Their modular design allows for easy integration into existing infrastructure, enabling industries to transition to sustainable heating without significant capital expenditure.

Economic and environmental benefits

The integration of MAN Energy Solutions' heat pumps into industrial systems offers both economic and environmental advantages. These pumps provide



Industrial-scale heat pump system by MAN Energy Solutions

up to 100 MWth of heating power, drawing from waste heat or renewable electricity. By capturing and reusing thermal energy, industries can achieve substantial reductions in their operating costs (OPEX) while simultaneously lowering CO_2 emissions. Furthermore, their high coefficient of performance (COP) ensures optimal energy efficiency, helping industries achieve a more sustainable operation.

Conclusion

As industries look to decarbonize and move toward a greener future, MAN Energy Solutions' heat pump technology provides a practical and sustainable path forward. By reducing both emissions and energy consumption, these solutions help industries meet regulatory targets while contributing to global sustainability goals.

https://www.man-es.com

Profinet actuator retrofit enables sustainable plant operation

AUMA's service team has installed 241 modern AUMA actuators in Stockholm's largest combined heat and power plant, Kraftvärmeverk 1 (KVV1), thus contributing to sustainable energy generation in the Swedish capital. The high-performance actuators equipped with Profinet interfaces ensure reliable, efficient plant operation and reduce operating costs.

The plant was originally built in 1976 for fossil fuels. In 2022 plant operator Stockholm Exergi initiated a large-scale retrofit project to modernise the plant and extend its service life by a further 20 years.

AUMA's experienced retrofit experts helped Stockholm Exergi find the most suitable electric actuation solution for each application.

Using AUMA actuators with integral Profinet communication brings major advantages: high reliability thanks to integrated redundancy, easy and flexible integration, transparent access to data via standard web technologies, and advanced diagnostic options.

The AUMA service team took care of the entire project management: from a detailed analysis of the requirements, through the selection and sizing of suitable actuators from AUMA's broad actuator portfolio, to installation and commissioning on site.

AUMA offers comprehensive retrofit services, helping plant designers and operators upgrade their existing plants with state-of-the-art, high-performance valve actuation technology. Examples include when a new control system is introduced, when new requirements for actuator diagnostics arise, or when manually operated valves need to be automated.

For more information on the AUMA Retrofit Service refer to retrofit.auma.com.

www.auma.com

Seamless transition from conventional radio technology to PoC communication in hazardous areas

ATEX/IECEx certified 5G radio IS440.1 of i.safe MOBILE enables seamless group communication

Private mobile radio networks (PMR) have been around for years. In consideration of the advantages of digital formats, there is a steady switch to digital PMR technologies. With 5G, it is now possible to rethink PMR and offer more flexibility, functions and security, which is a key priority in the Ex-area. With its new development, the ATEX/IECEx-certified 5G radio IS440.1, i.safe MOBILE is supporting customers in their industrial digitalisation strategy. The 5G radio ensures secure and failure-free PoC communication via public, campus networks (4G or 5G) or Wi-Fi®. The IS440.1, which has the look and feel of conventional radios, can be seamlessly integrated into group communication with existing devices (e.g. two-way radios: TETRA, DMR and analogue PMR) via a PoC bridge server. With the new development, i.safe MOBILE was focussing on data protection, security, flexibility, quality of service and reliability.

The 5G radio offers a user-orientated look & feel, a replaceable battery, large buttons for PTT, SOS, talk group selection, a powerful front speaker, an ISM interface and a functional fixing clip. The user can download selected apps that are compatible with the device directly from the pre-installed i.safe MOBILE App World and update them regularly. The App World contains product-related, selected push-to-talk and MDM solutions.

i.safe MOBILE is constantly endeavouring to respond to the needs of its customers in the Ex-sector and to always be one step ahead. **www.isafe-mobile.com**

Innovative Chemical PET Recycling

The Future of Sustainable Plastics with SMS Technologies

As the global focus on sustainability intensifies, the plastics industry faces increasing pressure to find alternatives to traditional recycling methods.

Buss-SMS-Canzler is at the forefront of this shift with innovative chemical PET recycling solutions.

Unlike traditional methods that simply melt and filter PET (polyethylene terephthalate), chemical recycling breaks down polyester molecules into their original monomers. Advanced processes such as hydrolysis, methanolysis, glycolysis and enzymolysis enable the recovery of valuable raw materials like terephthalic acid (TA) and ethylene glycol (EG), as well as pseudo-monomers like BHET or DMT. Through intensive, multi-stage purification, high-purity materials are produced, which serve as the base for new virgin PET (vPET), providing a closed-loop recycling solution.

The main challenge lies in the purification processes, where complex mixtures often exhibit high viscosity, crust formation or reactivity.

This is where Buss-SMS-Canzler's specialized equipment comes in. Their thin film evaporators, short path evaporators (see picture), and thin film dryers are designed to handle the most demanding steps of the recycling process, such as:

- Drying of terephthalic acid (CTA, PTA) after hydrolysis
- Evaporation of (di-)ethylene glycol (DEG/EG) from glycolysates and hydrolysates
- Evaporation of BHET from pre-concentrated glycolysates

These tailor-made solutions allow manufacturers to optimize their recycling processes, enhancing efficiency and product purity, while ensuring maximum reliability for sustainable, future-oriented recycling.

sms-vt.com

Revolutionize Your Crystallization Processes with the EKATO TORUSJET

Is your continuous crystallization process hindered by inefficiencies and suboptimal results?

The EKATO TORUSJET is here to transform your operations. Engineered for precision and performance, the TORUSJET is a high-performance impeller designed specifically for draft tube apparatus in continuous crystallization processes.

Unparalleled efficiency

The TORUSJET's flow-optimized blade geometry generates an exceptional axial pumping capacity, enabling the handling of large flow rates and significant head differences. This translates into:

- **Enhanced mass transfer:** Achieve rapid and uniform mixing, accelerating the crystallization process.
- **Superior product quality:** Produce crystals with consistent size and shape, improving downstream processing.
- **Reduced energy consumption:** Optimize your process efficiency and lower operational costs.

Gentle mixing for delicate processes

The TORUSJET's carefully designed blade geometry creates a low-shear flow field, making it ideal for handling sensitive materials. This gentle mixing action:

- **Minimizes product degradation:** Protect your valuable products from damage caused by excessive shear forces.
- **Prevents agglomeration:** Ensure a uniform particle size distribution.
- **Optimizes yield:** Recover more of your target product.

Tailored to your specific needs

EKATO offers a wide range of customization options to ensure the TORUSJET perfectly aligns with your unique process requirements. Our experts can assist you in selecting the optimal impeller design, materials, and dimensions to achieve maximum performance and longevity.

Key benefits of the EKATO TORUSJET:

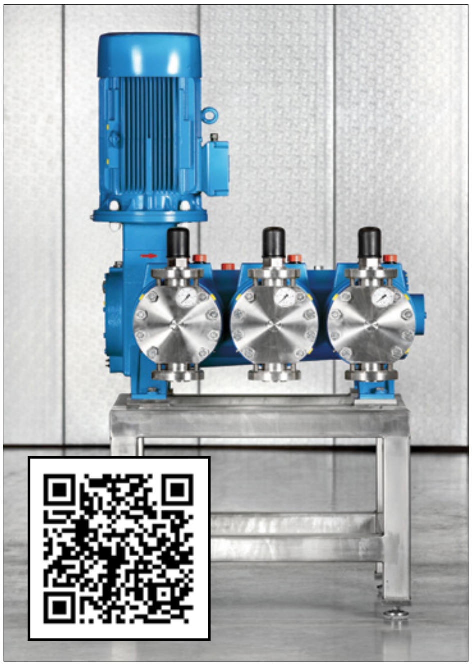
- High performance for continuous crystallization
- Exceptional axial pumping capacity
- Low-shear flow field
- Customizable design
- Improved product quality
- Reduced energy consumption

EKATO – Your Partner in Mixing Technology

LEARN MORE

www.ekato.com

HOT PRODUCTS



LEWA Launches Compact Triplex G3E Pump for Space-Limited Applications

LEWA introduces the triplex G3E, a compact triplex diaphragm pump ideal for fuel gas supply systems on ships and other space-constrained applications. Featuring a robust mono-block design, the G3E offers smooth metering and exceptional power output with around 30 percent space savings compared to modular pumps. Designed for medium hydraulic outputs, it provides a low-pulsation alternative to single-head pumps, with only 20 percent residual pulsation. This new pump can operate at stroke frequencies up to 350 spm, achieving a flow rate of 20 m^3/h at 16 bar, and pressures up to 400 bar at lower flow rates. The G3E's efficiency ranges from 80 to 90 percent, significantly reducing energy costs and extending the pump's lifespan.

More information:

www.lewa.com/en-DE/pumps/process-pumps/lewa-triplex-process-pump

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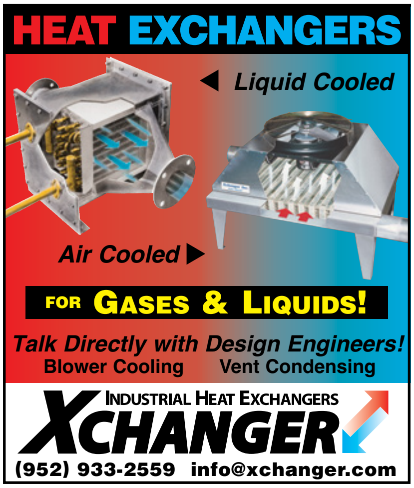

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Economic Indicators

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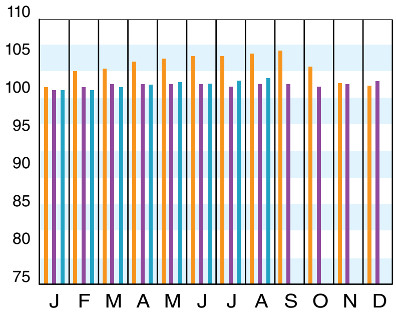
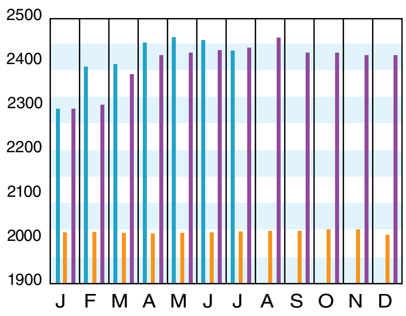
CURRENT BUSINESS INDICATORS	LATEST			PREVIOUS						YEAR AGO		
CPI output index (2017 = 100)	Aug. '24	=	100.7	Jul. '24	=	100.2	Jun. '24	=	100.0	Aug. '23	=	99.7
CPI value of output, $ billions	Jul. '24	=	2,438.3	Jun. '24	=	2,417.9	May '24	=	2,421.7	Jul. '23	=	2,355.9
CPI operating rate, %	Aug. '24	=	77.3	Jul. '24	=	77.1	Jun. '24	=	77.0	Aug. '23	=	78.1
Producer prices, industrial chemicals (1982 = 100)	Aug. '24	=	312.1	Jul. '24	=	312.0	Jun. '24	=	305.2	Aug. '23	=	307.0
Industrial Production in Manufacturing (2017 =100)*	Aug. '24	=	99.6	Jul. '24	=	98.7	Jun. '24	=	99.4	Aug. '23	=	99.5
Hourly earnings index, chemical & allied products (1992 = 100)	Jul. '24	=	229.2	Jun. '24	=	228.7	May '24	=	228.4	Jul. '23	=	225.0
Productivity index, chemicals & allied products (1992 = 100)	Aug. '24	=	94.8	Jul. '24	=	93.1	Jun. '24	=	93.3	Aug. '23	=	93.0

2022 2023 2024

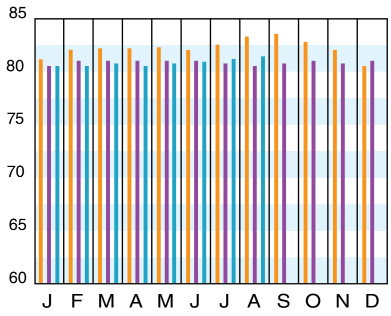
CPI OUTPUT INDEX (2017 = 100)†



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



*Due to discontinuance, the Index of Industrial Activity has been replaced by the Industrial Production in Manufacturing index from the U.S. Federal Reserve Board.
†For the current month's CPI output index values, the base year was changed from 2012 to 2017
Current business indicators provided by S&P Global Market Intelligence, New York, N.Y.